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CHARACTERISTICS OF URBAN TERRAIN

LEVEL II

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Characteristics of Urban Terrain, expands upon findings displayed in a previous study (Urban Building Characteristics, Ellefsen, 1977) completed for the Naval Surface Weapons Center, Dahlgren, Virginia. Results reported here are far more detailed in every respect. For instance, exact figures are given for such building characteristics as thicknesses for exterior walls and interior partitions of varying types; the previous study provided data within ranges. Data reported earlier were subjected to intensive analysis and are presented — cont

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here in expanded form, both graphic and tabular. Broad, new conceptual notions concerning the environmental setting for buildings were explored, measured, analyzed, and presented in a variety of graphic ways. Findings are presented which have potentially very high value for consideration of conducting military operations in urban areas.

FOREWORD

The work described in this report was authorized under contract number N60921-78-R-A118, Urban Building Characteristics. The work was conducted between July 1978 and June 1979. This study is the second in a series. The first, Urban Building Characteristics, was published as Naval Surface Weapons Center Technical Report 3711, available from DDC (AD-B021610).

This report has been reviewed and approved by L. E. Wicks, Program Manager, Systems Engineering Branch; D. A. Wilson, Head, Systems Engineering Branch; and C. L. Dettinger, Acting Head, Gun Systems and Munitions Division.

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PREFACE

Appreciation is expressed to the Naval Surface Weapons Center, Dahlgren, as sponsors of the project and particularly to Larry Wicks, contract monitor, for his many suggestions and assistance. The offering of useful ideas from all the staff of Systems Engineering at NSWC is also greatly appreciated. The encouragement by Morley Shamblen and Alan Alexander is especially appreciated.

Considerable help and encouragement was also given by several other members of the MOBA community and specifically colleagues from the Human Engineering Laboratory at the Aberdeen Proving Ground, Don Egner, Ellsworth Shank, and Brenda Thein. Orbin Larson from the Navy Personnel Research and Development Center offered many suggestions and posed valuable questions concerning air operations in cities. Special thanks is also offered to Marine Corps personnel Majors Sean Del Grosso and Michael Janay for their comments and interest. The helpful suggestions of George Schecter, Analytics Corporation, are also acknowledged.

Special appreciation is given to co-workers on the project, Thomas Kuhn and Gary Spring, graduate student assistants in the Department of Geography, San Jose State University. They worked long hours and devoted countless evenings and weekends to the project. Without their contributions in data gathering, analysis, and graphic presentation, the project would not have been possible.

Finally, the views expressed in this paper are mine. For these I accept full responsibility.

Richard Ellefsen

CONTENTS

1.0 EXECUTIVE SUMMARY

This work, Characteristics of Urban Terrain, expands upon findings displayed in a previous sutdy (Urban Builuing Characteristics, Ellefsen, 1977) completed for the Naval Surface Weapons Center, Dahlgren, Virginia. Results reported here are far more detailed in every respect. For instance, exact figures are given for such building characteristics as thicknesses for exterior walls and interior partitions of varying types; the previous study provided data within ranges. Data reported earlier were subjected to intensive analysis and are presented here in expanded form, both graphic and tabular. Broad, new conceptual notions concerning the environmental setting for buildings were explored, measured, analyzed, and presented in a variety of graphic ways. Findings which have potentially very high value for consideration of conducting military operations in urban areas are presented.

Two principal subjects are examined. The first concerns urban buildings and is subdivided into the two sections of (1) architectural characteristics, and (2) characteristics of walls. The second major section treats various forms of areal patterns such as building placement, street widths, lines-of-sight, and open spaces.

1.1 SUMMARY OF RESULTS

Key findings are described under the chapter headings used in the report. Graphs and tables provided in the text provide specific data.

1.1.1 Architectural/Structural Characteristics of Buildings

Well demonstrated throughout the report is the binding relationship which exists between a building's architectural/structural form and the arrangement of its interior. Equipped with a knowledge of a building's type of construction, its function, and its outside appearance, it is possible to predict the nature of its interior with a high level of reliability. Numerous diagrams illustrate theoretical sizes and arrangements of rooms, hallways, and service modules. These are supported by data from measured, reported real cases. Average sizes of rooms, per function, add further evidence.

In a similar vein, generalized findings are presented on the nature of building venting. Based on projections on building construction characteristics and function, it is also possible to establish principles concerning size, shape, and patterns of a building's windows and doors. Diagrams illustrate the situation, and ancillary data from measurements lend support.

1.1.2 Characteristics of Building Walls

A major early concern among military planners examining the nature of urban terrain has been the constructional type and thickness of building walls.

The possible need to breach walls (or to use them in a defensive posture) has required data on their nature. These are provided in the study for buildings of all of the subtypes of the two major classes of frameless and framed. For example, thicknesses of brick walls (for structures of varying heights) are given, as are data on several types of cladding for framed buildings.

1.1.3 Urban Spatial Patterns

The fair portion of a city's area which is not built upon has a high potential military significance for it is the area important in circulation, ground and air traffic, and supply and deployment. The chapter identifies these areas, describes their nature, measures them, and places them in a military context. Key attention is paid to line-of-sight characteristics both along and across streets and across open spaces. Data are provided, such as the figure (taken from measurements in 16 international study cities) that nearly two-thirds of all streets have widths ranging from 15 to 25 m.

Important differences in line-of-sight distances occur, however, within the city. Diagrams illustrate the types of situations which occur in residential areas of various types, commercial-industrial districts, and newly built outer-city units.

Special emphasis was given to a test case, Bremen, FRG. Measurements were made of along-the-street lines-of-sight resulting in a general mean of 162 m (for the older section of the city). For the same area, the across-the-street line-of-sight distance was 17.4 m.

Lines-of-sight distance data were used to address the problem of the suitability of employing shoulder-carried assault weapons. Extreme narrowness of some of the streets entertains the risk that there are areas in some cities where weapon usage of certain types may be precluded. Some variations occur, however, at corners and street intersections. Drawings indicate the nature of the situation.

An attempt to develop useful methodology to apply to large numbers of cities was made by providing data on the ratio between surface space on the street to building floor space. Theoretically, the higher the proportion of floor space to street, the greater the degree of difficulty to potential military operations. Bremen and Casablanca are measured test cases.

Another consideration of non-built-upon area was presented regarding the nature and pattern of open spaces within a city. Quite remarkably, for the 16 cities studied, open spaces near the center of a city demonstrate a high level of universality. Mean sizes and mean distances apart vary but little. Knowledge of this phenomenon could be useful to military planning.

Yet another example of spatial patterns in the city is expressed in the investigation of the nature of the periphery. For two test cases, Bremen and San Jose, Costa Rica, (representing two varied approaches to the problem of urban expansion), it was seen that there are measurable dimensions to the contiguously built-up part of the city and to urban exclaves in the surrounding

countryside. Urban exclaves can be considered as fortification "redoubts" and would probably play a key role in defense of a city's perimeter. Intervening open spaces can be considered to be a series of "moats" (open fields-of-fire) which would have to be crossed by an advancing force. Knowledge of the nature of these phenomena, such as the types of buildings present, their density, and an evaluation of their resistance, could be potentially very useful.

1.2 CONCLUSIONS

After full examination and analysis of the data gathered, the following conclusions were reached:

a. Characteristics of buildings and their settings have potentially high value to the possible needs of military activity in urban terrain.

b. Universals among cities are more important than local differences. Cities of a given size are similar despite the general nature of the country in which they are located.

c. Building characteristics are strongly tied to the form of construction and to the intended function, and these vary but little from place to place.

d. The basic classification system (employed in the earlier study) is sound and should be applied in any further use.

e. The interior characteristics of a building may be predicted by observing salient features of the exterior.

f. Buildings facing street corners frequently have a character which may be of considerable importance to tactics planners.

g. A definite order exists in wall thicknesses and construction form for walls of various types regardless of where located.

h. The nature of cladding in framed buildings, although generally light in strength and resistance, could be more important than formerly considered.

i. It is now possible to forecast the total amount of wall breaching which might be necessary in a given sector of a city.

j. The interior partitions of buildings are fairly universal in character and their potential role in intrabuilding military operations can be known.

k. A definite order exists in the pattern of non-built-upon space within the city.

l. Average lines-of-sight are related specifically to certain types of buildings and to certain functional zones.

m. Little difference occurs from place to place (one large city to another large city) in the world regardless of the nature of the countries.

n. Patterns of urban development at the edge of the city do vary regionally and are in accordance with national policies and cultural differences. Military planning needs to take note of these and to study regional variation.

1.3 RECOMMENDATIONS

Analysis of the findings has led to the development of several recommendations. They are:

a. Full assessment should be made of just where and how much breaching of walls might possibly be required. Application of data from the study (plus methodology developed) would allow the making of such an evaluation.

b. Building settings, relative to the wall breaching, should be considered to determine the type of weapon and tactic which would be required.

c. The documented universality of open spaces should be brought fully into the planning process as it bears upon transportation, tactics, and logistics.

d. An index which relates street area to floor space should be developed for a number of cities and situations.

e. A refinement should be developed which employs the variables of declining military usage with increasing building height and the fortifiability of a structure.

f. Further consideration should be given to the possible implications of street intersections and corner building configurations.

g. All of the types of walls identified in the study should be simulated and used in test firings of weapons. This includes varying weapons and both walls and partitions.

h. Consideration should be given to developing a match between type of target and weapon and warhead to be used.

i. Consideration should be given to cladding (both light and heavy) which is applied to framed buildings. Some of the heavy cladding could cause more difficulty than had previously been supposed and should be tested. Angles at which concrete cladding is placed (some of which reaches 20 cm in thickness) on exteriors of modern buildings could also present a problem.

j. Building venting (windows and doors) should be simulated and used in test firing at various angles and distances to determine their potential as targets and what bearing they have upon weapon sighting.

k. Attention should also be given in a testing situation to the character of building interior partitions. Some are possibly more resistant than previously thought. Another need is to relate them to possible tactical situations.

l. The cones-of-fire based on given minimum arming distances, lines-of-sight, and angles of obliquity need to be considered in a testing situation.

m. The findings should then be further related to the expected locations where they might be fired to determine relationships of adjacent rooms to the back-blast problem.

n. All the component spatial features of a city should be considered in tactics planning for advance upon (or defense of) a city. "Redoubts" and "Moats" should be examined further for additional cases.

o. Training areas, either models or simulated full size, should consider the findings of the study to aid in design and planning.

2.0 INTRODUCTION

This study is the second in a series. The first was Urban Building Characteristics (Ellefsen, 1977) which appeared as a published research report written for the Naval Surface Weapons Center, Dahlgren, Virginia. The study presented pertinent data on building characteristics and their settings for 16 selected international cities. Data were derived in part from published sources in architecture and structural engineering and in part from observations made in the field. That study served several subsequent purposes for various members of the community interested in military operations in built-up areas (MOBA)*. It also resulted in the flagging of several areas of interest requiring further study and procurement of additional data. All of these and more were investigated in this study.

The method employed was to direct the research to pointed questions concerning the three topics of (1) building architectural characteristics, (2) wall configurations and dimensions, and (3) spatial patterns of urban phenomena. All were examined, measured, analyzed, and related to specific matters of military concern. In the course of study, many new items of data were found and used in addition to the use, further manipulation, and analysis of data from the original study. A high level of detail was emphasized throughout. In examples of real cities, precise measurements were made of such features as street widths, horizontal lines-of-sight, and wall thicknesses. Detailed published engineering sources were sought and used.

In the course of seeking to provide specific answers to tasks specified in the contract, several serendipitous results surfaced. These, in turn, led to some new thinking about the nature of the city as a potential site for military operations. Set against interests indicated by users at meetings of the Military Operations Research Society and elsewhere, several ideas were generated concerning innovative ways to examine the urban environment to attempt to learn more about its characteristics relative to military needs.

Thus, there results from this study a particular set of data designed to answer specific contract requirements plus material which could be useful in helping to answer a variety of questions raised in the MOBA community. Some of the conclusions concerning these latter items are tentative, suggesting yet further investigation.

Some of these questions relate to urban buildings as potential targets, some to the nature of the environment in which these buildings are located, and some to the broader spatial patterns of whole metropolitan areas. A few examples will serve to illustrate. It is postulated, for example, that such a strong relationship exists between the interior arrangement of buildings

*The term MOBA is used throughout the study, not in ignorance of or disagreement with the term MOUT (Military Operations in Urban Terrain) but simply because it is universally understood.

and their architecture that it is possible to forecast, with considerable precision, what to expect on the interior of a building by noting salient points of the exterior. For another example, the variety of building materials, although great, replicates almost universally. Because of this, it would be possible to develop a set number of target types which would meet all possible testing and training needs. Yet another example is that the environmental settings of buildings of certain types may be known and that this knowledge could possibly be treated by computer manipulation to arrive at the best possible solutions to field problems.

3.0 ARCHITECTURAL/STRUCTURAL CHARACTERISTICS OF BUILDINGS

An understanding of the nature of buildings, whether it be for military purposes, civilian needs, or simply acquiring academic knowledge, can be gained only through an appraisal of the multiplicity of factors which bear upon design and structure. Acting in an interlocking fashion are parameters which, in the aggregate, dictate the shape, size, height, structural characteristics, function, and overall appearance of a structure. The variations from time to time and from place to place within each parameter plus the nearly infinite combinations cause building forms to vary widely in the world's cities.

Fortunately, for purposes of classification, fairly universal conditions have prevailed in architecture, structural techniques, and building function globally for a long enough period of time to cause basic, replicative patterns. Many buildings have, in fact, been built in major cities by multinational construction companies, further dispersing types and promoting universality. At the very least, architectural designs and building technology have historically been widely transferred from one country to another. It is not surprising to find the same kind of structures in such disparate cities as Hong Kong, Sao Paulo, and Johannesburg.

A diagram (Figure 1) is designed to illustrate how major parameters bear upon the characteristics of a building. The architect's concepts and designs (upper left) are widely recognized as being of key importance; note that an architect's name or firm is normally credited before that of the construction company. The architect's objectives are to produce an artistically pleasing structure which meets his client's functional space needs while conforming to the constraints of structural possibilities, costs, and other design requirements which are strictly codified and enforced by public agencies. Building configurations also vary through time and indeed are often symbolic of a period. The age of the heavy, ornate skyscraper of the American city of the first third of this century is quite different from that associated with the low-rise masonry structures of European cities of the latter nineteenth century.

The structural engineer also has a vital role to play in affecting building characteristics. He is primarily concerned with the structural integrity of the building but working within the cost limitations of his clients. He attempts to produce, in an economic way, all of the design elements stipulated by the architect. While classic confrontations have sometimes arisen between the two, the net effect of compromise is important in understanding the completed building. The engineer is responsible for selection of the materials of the structure. Beam and column configuration and strength plus the method for tying them together are vital to the building's ability to withstand vertical and horizontal forces. The thickness of weight-bearing walls and of decorative cladding is also considered. Taken together, a knowledge of the physical nature of the building is of vital importance to understanding its military significance. A structure's strength and weakness may be applied to military planning problems.

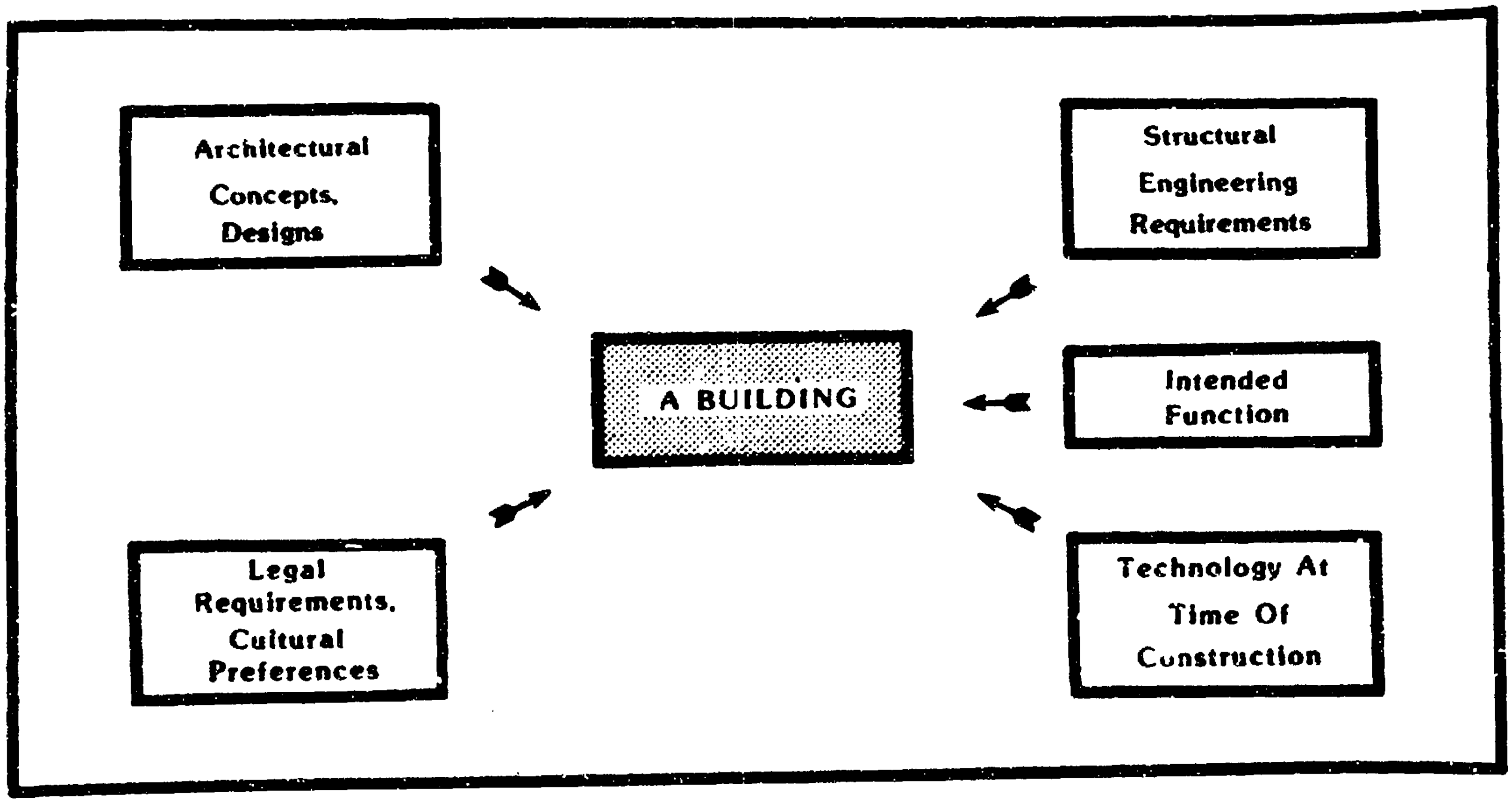

Figure 1. Factors Affecting a Building's Design and Structure

Function also plays an important role in forming a building's characteristics. Requirements for space in varying configurations result in several types of buildings. Fortunately, however, for purposes here the possible functions are relatively few in number and are universal. The need, for instance, for storage space to support industrial and wholesaling functions is the same both for developing and developed nations. Office and hotel space division is also essentially the same everywhere.

An understanding of the historical perspective is also important. Because of the longevity of buildings, virtually all cities have whole sections where buildings of a particular period are extant. Common in all of the cities previously studied are areas where buildings of varying eras predominate. For instance, vestigial brick building areas are found in one section of a city, heavy-cladded frame structures in another and tilt-ups in another. Each is related to a particular span of years when certain designs and structural engineering practices were employed. Helping to segment time are the natural breaks caused by war, depressions, and rapid introduction and acceptance of breakthroughs in building technology.

As a final parameter in the diagram, legal requirements and cultural preferences have an impact on building configuration. Sometimes as a result of such major events as war and natural disasters, whole sections of cities reflect departures in building codes. Cultural preferences may manifest themselves in building design which reflects symbolic national characteristics. The "heavy" style of architecture of the Soviet Union and the use of the traditional pitched roof in modern concrete-framed buildings in Germany are good examples.

3.1 GENERALIZED SPATIAL PATTERNS OF BUILDING TYPES

The interplay of the above factors also accounts for a regionalization of building types within the city. A principal force is the market place. The extremely high value of the most centralized land in the center of the city (the downtown) has led to a process of constantly replacing older, smaller, less economic structures with taller, more efficient buildings. The multiplication of the finite amount of available centralized surface space through the device of adding more floors to a building has resulted in an ever taller skyline for most cities. To meet this need, framed buildings which could reach heights of 100 and more floors replaced masonry wall, mass structures with their inherent height limitations of but a few floors. New sections of cities always reflect the building technology of the period of their construction. New wholesaling and light industrial sections are today composed very largely of either concrete-framed or concrete tilt-up structures.

The generalization can be made about cities throughout the world that distinctive areal patterns of building types and functions exist. These morphological/functional regions of a large proportion of cities are readily identifiable and follow generally replicative patterns. A generalized model of a modern city in a country with a fairly long urban history consists of the zones of:

a. Tall, steel- or concrete-framed buildings with light cladding in the center of the city on the highest value land.

b. An adjacent area of framed (steel or concrete) buildings with heavy cladding. These are fairly tall but not as tall as the previous class and are located on land of slightly less value.

c. An area of masonry buildings, vestiges of a period when a city was composed mostly of such structures. Height is restricted to but a few floors. Uses are varied and rents are considerably lower than in the previous two classes.

d. An area of framed (usually concrete) buildings used for storage and light industry. These have traditional central business district "frame" uses such as the selling of office furniture, housing the printing trades, or being warehouses.

e. Beyond this are the city's residential areas. Nearer to the center are the older, often multiple-family structures (many of which are converted from once single-family houses).

f. Yet farther away from the center is the newer industrial area composed mostly of either concrete-framed or concrete tilt-up buildings.

g. Farthest away from the center is the sprawl of suburban housing. Building architecture and structure are products of local styles and building materials; some are mass-construction (usually brick) while others may be light framed.

The general types and their basic characteristics, as identified in Urban Building Characteristics, are seen in Table 1.

Table 1. Principal Building Characteristics

Type of Construction	Building Material
Frameless	Stone
	Brick
	Concrete Block
	Concrete Wall and Slab
	Concrete Tilt-Ups
Framed	Wood (Balloon)
	Steel/Concrete (heavy cladding)
	Steel/Concrete (light cladding)

3.2 BUILDING INTERIORS

The arrangement of interior space within a building is a direct product of its design, method of construction, and intended function. Because these parameters--an extension of those discussed above in connection with the entire building--are universal, it is possible to forecast the interior arrangement of a building by knowing its constructional type and function as identified by observation from the outside. Numerous examples follow which demonstrate the great differences in interior spatial arrangements.

3.2.1 Frameless Structures

Buildings whose principal structural strength is borne by exterior load-bearing walls have interior arrangements which are not related to a supporting frame (as it is with framed structures). Accordingly, there is great flexibility in the design and use of interior space. Function, rather than form, becomes the predominate factor. The interior may be completely open and without partitions or columns if the function so requires (a gymnasium is a good example).

The simplified model of a multistory brick building (Figure 2) demonstrates the principle. The exterior load-bearing walls are thick enough to support their own weight and that of the floors and roof; variations of thickness with building height appear in Chapter 4.0. A secondary support to floor/ceilings is provided either by columns or by load-bearing partitions in instances where fairly large interior open spaces are required.

Floor plans are thus primarily a product of the usage intended in the original architectural design of the building. Due to the widespread use of this form of construction all over the world for such a long period, examples of almost every possible type of function may be found. Still, a commonality is identifiable and serves as a base for the making of useful generalizations.

Brick structures are widely used for retail stores. In such use there is a demand for unrestricted open space for the display and selling of merchandise. Small retail stores (a common situation along commercial streets where each merchant holds access to the passing trade as essential) are invariably so narrow that the beams crossing over the two sidewalls are sufficiently short to support the roof load without the need for interior columns or partitions. Larger stores are multiples of this minimum distance (no more than 7 to 10 m) and thus require columns to augment the strength of cross beams. Columns in such instances, considering that the buildings in which they are found were built in the last century, are commonly made of iron.

Reference must also be made to the axioms which dictate the functional use of buildings. Most of the brick buildings still used for office purposes in the U.S. were constructed before corporations were large enough to warrant individual buildings. Multiple story buildings (almost invariably located along major streets) were devoted to usage as retail while upper floors were designed either to be used for general offices, if the buildings were located

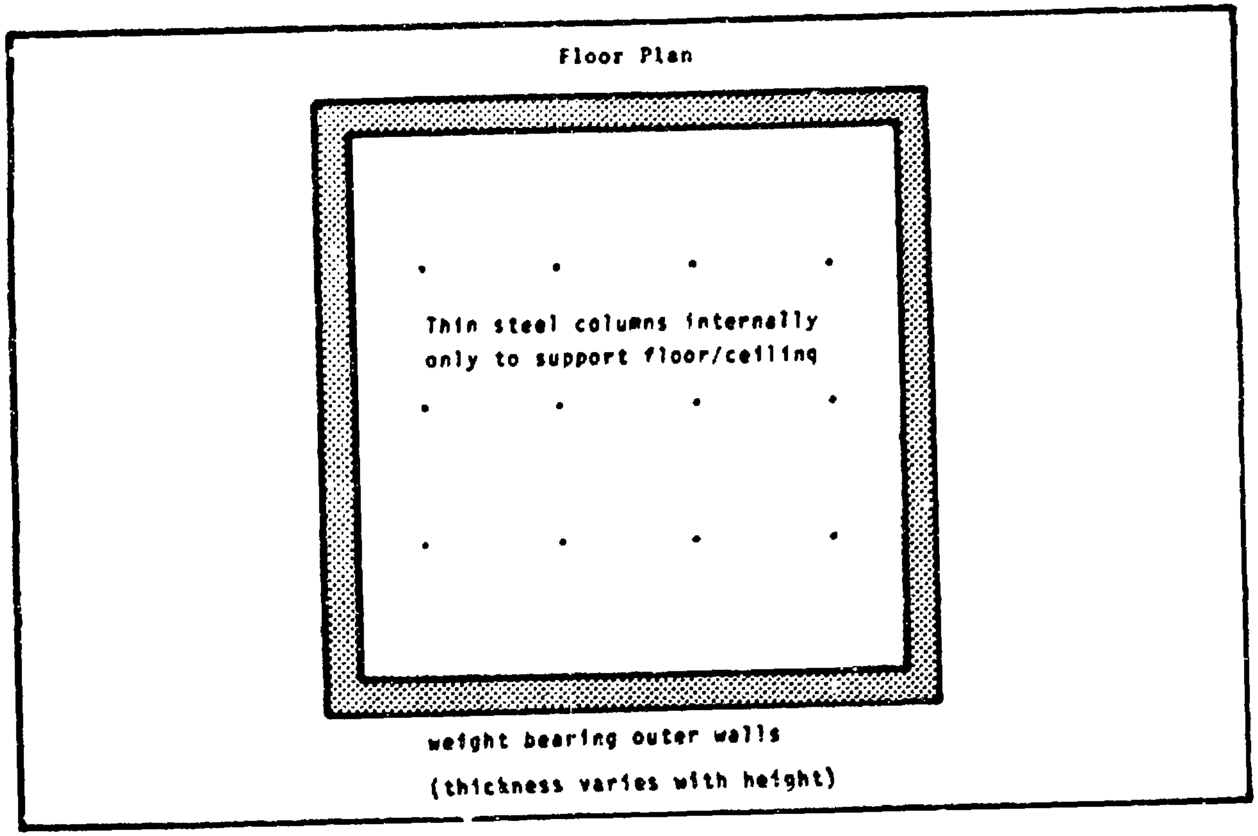

Figure 2. Structural Anatomy of a Multistory Brick Building

in areas of commercial concentrations, or residential if away from such areas. Thus, the common situation for buildings wider than 4 or 5 m was for them to have a retail store or stores on the street floor with interior columns to support upper floors. The upper floors were partitioned into small units, either offices, hotel rooms, or apartment rooms. The partitions of these were ordinarily made of wooden studs covered with lath and plaster (see Chapter 4.0).

In parts of the world where brick construction is still practiced for buildings of moderate height (two or three floors), the same conditions obtain. In such cities, it is the commercial center which has the modern steel or reinforced-concrete-framed buildings of greater height. Such structures present the only way for builders to offset the high cost of land in city centers. Thus, the brick structures are placed along lesser commercial streets. Again, the ground floor is used for retail purposes and upper floors for offices or human habitation. Ground floors are more open, depending on building width, and upper floor interior use is segmented.

The wide range of possibilities for arrangement of interior space is much the same for reinforced concrete tilt-up structures as it is for mass construction brick buildings. Again, the strength of the load-bearing exterior walls is augmented by steel (instead of the iron used in early brick buildings) columns to support the roof.* For economic reasons, walls are kept as thin as possible. Buildings of considerable size (for warehouses or structures for light industry) which reach heights (nominally no more than two stories) of 8 to 10 m have walls which range from only 14 to 25 cm in thickness.

To date, tilt-up buildings--although their form of construction offers considerable savings in labor costs over poured-in-place reinforced-concrete-framed construction--have been used primarily for structures whose principal objective is to provide large, open interior spaces. Storage is a common function (see Figure 3). In such structures, the usual single floor configuration is desirable because of the use of forklift trucks to move and stack goods on pallets. The narrow, aligned roof-supporting columns offer no serious impediment to use. Light industry finds such quarters similarly satisfactory. If any partitions are desired, they may be made of thin material. The modularity provided is a plus in the configuring of the space to meet client needs. The use of such structures for large retail stores is also facilitated by the type of construction; interior support columns are readily enclosed by racks of displayed merchandise. The usual partition separating goods storage from sales area is non-load-bearing and may be free-standing. The tilt-up form of construction even lends itself to the forming of decorative aggregate on the exterior walls while the wall is under construction on the floor of a building under construction.

As the evolution of tilt-ups goes on, there have been several instances of their use for offices and other forms of segmented interior space. In these

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*Newest construction is employing pilaster (column-like) members of reinforced concrete which connect concrete panels and help to support roof loads.

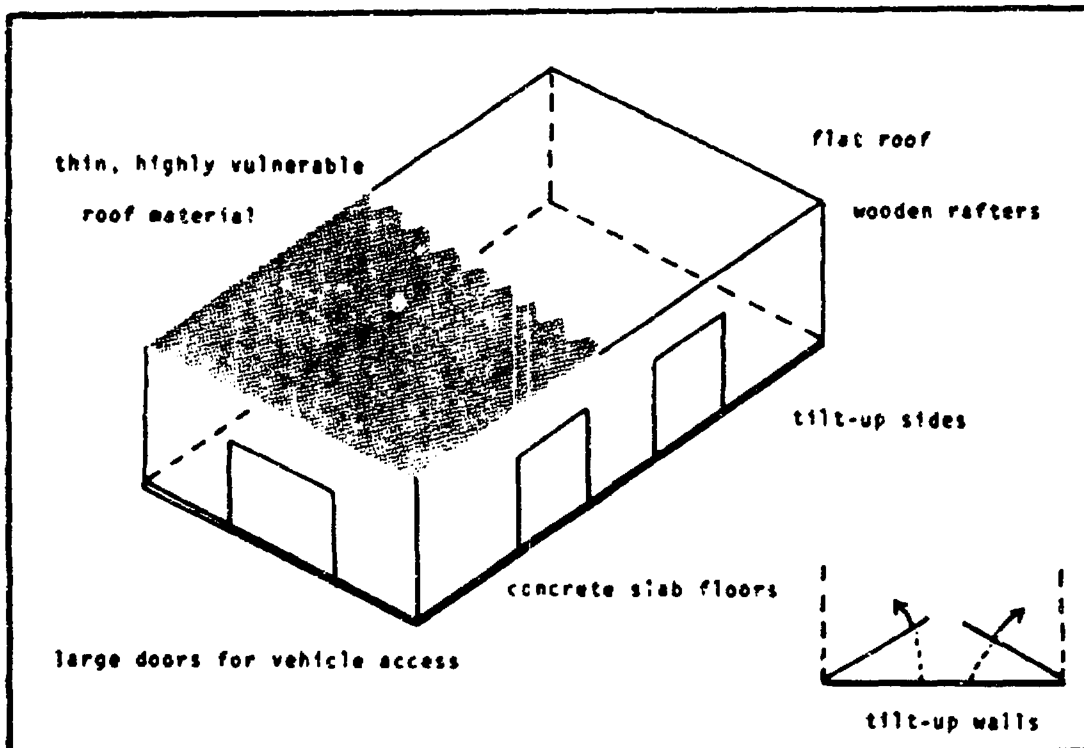


Figure 3. Concrete Tilt-Up Structures (Mostly Storage and Manufacturing)

cases, which usually rise to two stories, heavy support is required for the load of the second floor, though this support occurs within the tilt-up outside shell. Interior support varies with anticipated live loads of the second floor. For example, offices expecting large loads of paper require heavy support.

Because of the recent age of tilt-ups, they are located almost entirely in newly developed sections at the edge of the city, near dock areas, or major airports. Many are found in what were formerly referred to as industrial parks but, reflecting their increasing usage for offices, the name business park is becoming common.

Another type of mass construction with an even more predictable interior design is the wall and slab. This type of construction is sometimes called "cross-wall" (Joedicke, 1962, p. 40) or "box-wall principle" (Arregar, 1967, p. 130). With its load-bearing interior walls (at the exterior of each cell of which the structure is composed), room sizes are small. Further, the role of the wall to act in consort with all the other identical walls of the structure means that there is no flexibility of interior space use. It is permanent and fixed at the time of construction. The most appropriate function for these structures is some form of human habitation such as an apartment or hotel; widespread use of wall and slab structures for hotels all over the world virtually turns the style into a cliche. So very common is the interior arrangement seen in Figure 4 where individual cells (the guest rooms of a hotel) flank both sides of a central corridor. The exterior wall is very often made mostly of glass to allow light into an otherwise windowless room. Small balconies are common for both apartments and fancier hotels. A lower cost variation on the theme for motel construction has outside corridors with two paralleling rows of wall and slab cells in between.

In all these instances, room shapes and sizes are fairly uniform the world over. The shape is necessarily rectangular. For motels and hotels the dimensions are nearly the same everywhere (about 3 m wide and 4 m long, exclusive of baths and closets). Shape varies somewhat when apartments use this form of construction, with daytime occupance areas being larger than sleeping rooms. In Arregar's study (1967, p. 140-182) of 22 apartment buildings (both concrete-framed and wall and slab) in Switzerland, FRG, France, England, and Australia, the average size of rooms (1,861 total) was 17.2 m^2. In the example of a high-rise wall and slab building in Neue Vahr (at the periphery of Bremen) the individual flats ranged from 10 by 3.4 to 10 by 5.9 m.

Although they form a very small portion of the total buildings in cities, stone structures deserve some mention for they are invariably important buildings such as cathedrals or major government structures. Their style is usually classic and they often employ the traditional stone arch to support ceiling loads. Since this form of construction has a more artistic appeal than that of a framed structure, they are widely written about and illustrated in architectural literature.

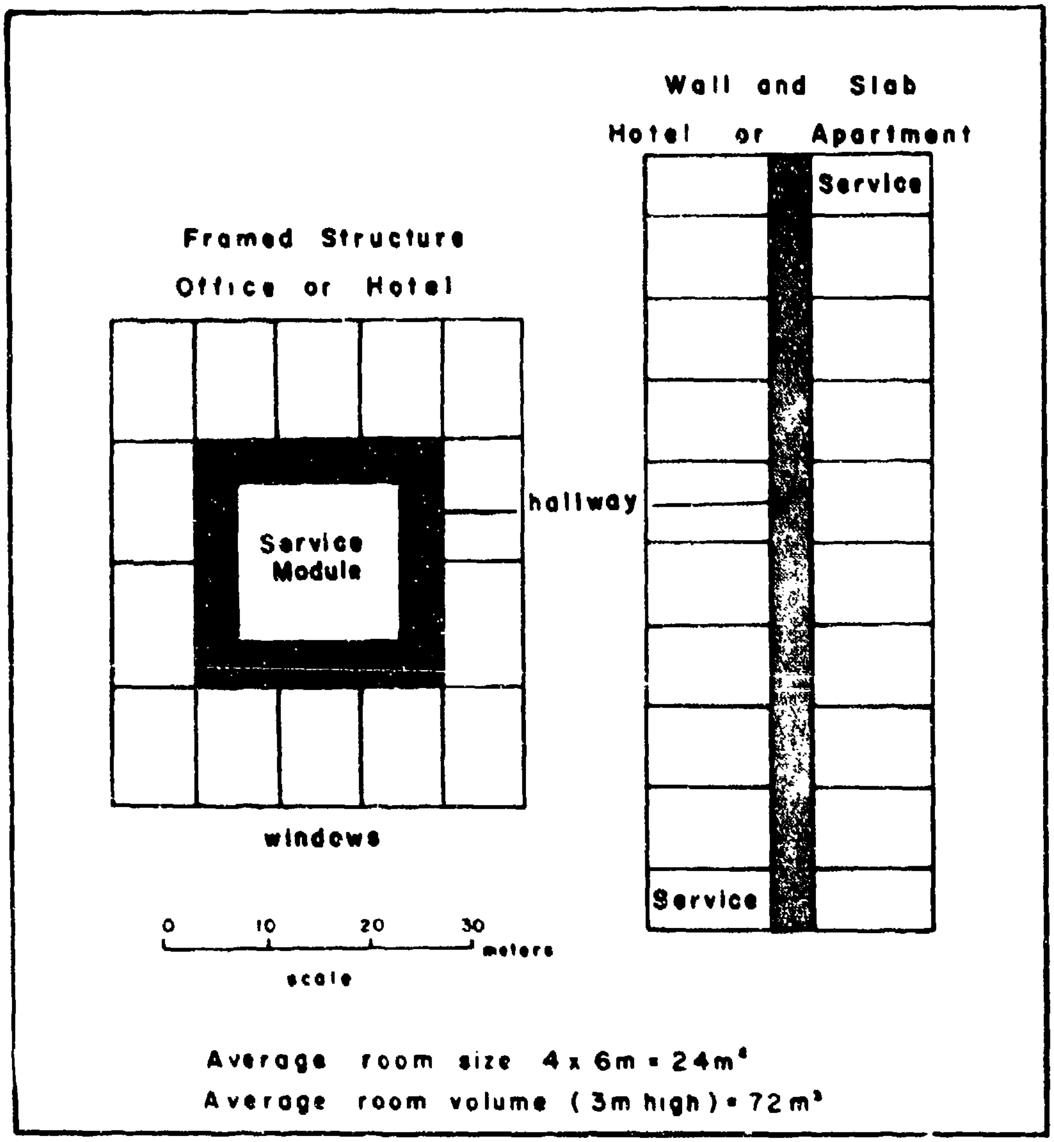


Figure 4. Architectural Factors Affecting Size and Configuration of Building Interiors
Access to Natural Light

The reason for the vaulted ceiling, traditionally that of supporting a large roof to cover broad interior space, usually means that the structure was intended for public purposes and accordingly has only one major room as in a church or perhaps an open space under a dome of an institutional building. The partitioning of space into lesser, smaller rooms usually follows the convention mentioned before with brick structures. Columns or partition walls may be used to support the floor immediately above.

3.2.2 Framed Structures

As with the frameless structures, a relationship exists between interior configuration and framed structures. The use of a frame to bear loads opened the way for more flexible usage of interior space than was true of the masonry buildings of before: today, framed buildings still offer more versatility in use of interior space than is the case with wall and slab construction. Architects say that the framed building provides a better solution to the architectural need for flexibility in the planning of interior space. Joedicke (1962, p. 40) says that "rooms can be given any desired arrangement." This notion of flexibility, however, refers to the options of placement of non-load-bearing partitions. Even though this is so, the very format of the framed structure--in its various subtypes--has tended to dictate a uniformity of interior space arrangement to the degree that generalizations may be made and that the plan of the building may be inferred from recognizing its salient external features.

This capability to predict is enforced by knowing that the interior arrangement of a building is fully considered during the design of every aspect of the structure. Partitions, for instance, in the older steel-framed (heavy cladding) buildings were designed to be placed along beams and columns. The selection of a 4-m interval between columns, for example, was related to a desired room width of 4 m. Venting was also part of the total design package. Window casings (varying in style and number as indicated under the section of the chapter devoted to the subject) were obviously placed in between columns and not across them.

The strong influence of the type of structure on interior space configuration is seen in the example of ground and upper floors (Figures 5 and 6). In this model, taken from observations in the Security Pacific Bank building in Los Angeles, it can readily be seen that a modern framed building which has a central column providing part of its basic support and a series of load-bearing peripheral columns for the balance can have little variation in its basic interior configuration. Even though there is a width of 12 m in between central pylon and outer columns in which interior space can be arranged, there are only two practical solutions for office design on the upper floors. They may either be large, open-bay type units with direct access to elevators for the entire floor or they may be divided into smaller offices which require a hallway around the pylon for access. The ground floor of this and similar structures everywhere is often retained as a large open space. Such space may be used as a lobby or for displays. Ceilings are generally high, usually the equivalent of two of the upper floors.

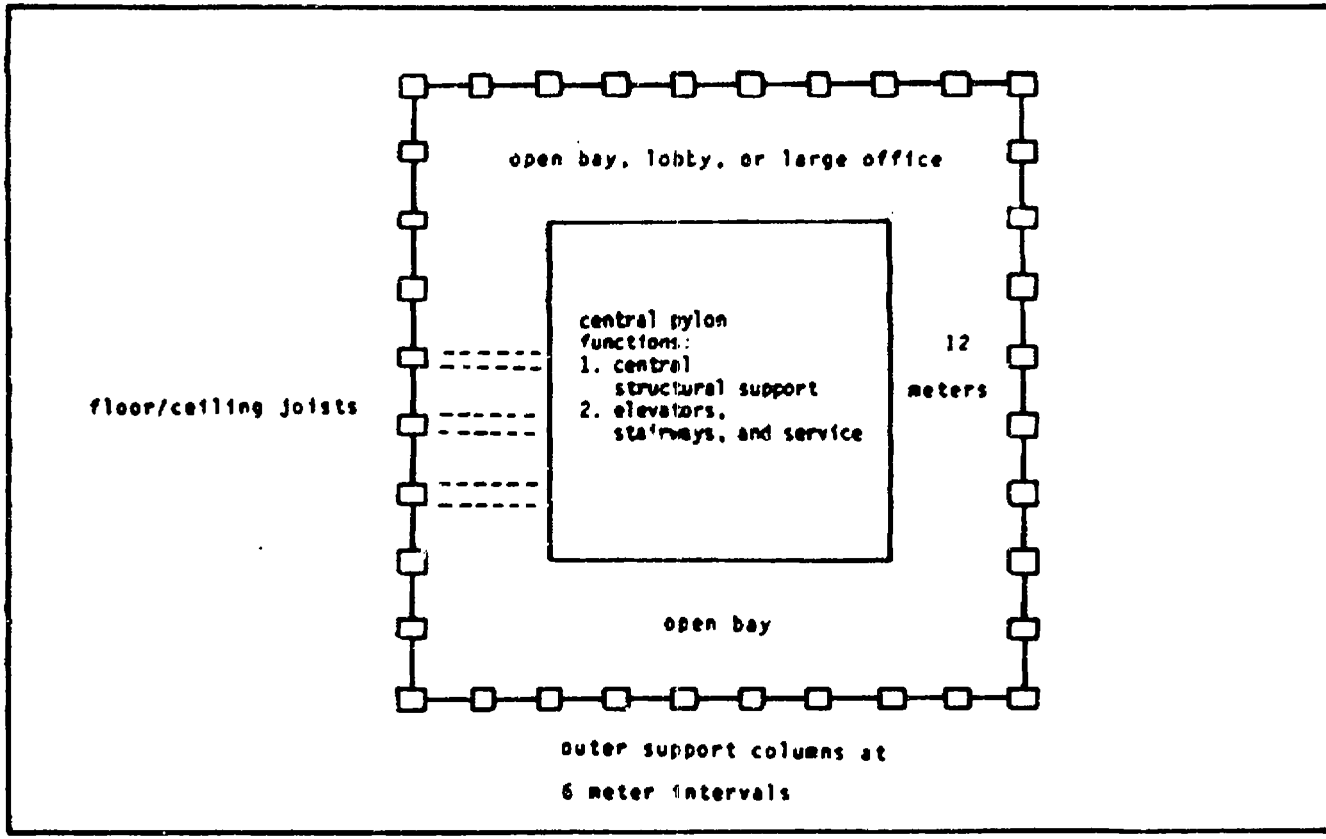


Figure 5. Steel/Concrete-Framed Tall (30+ Stories) Building with Central Pylon and Light Cladding Typical Ground-Floor Plan

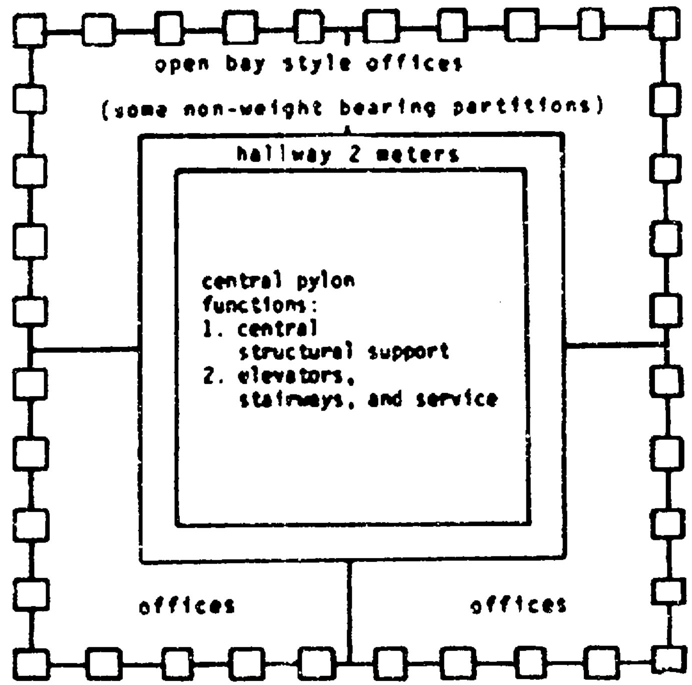


Figure 6. Steel/Concrete-Framed Tall (30+ Stories) Building with Central Pylon and Light Cladding Typical Upper-Floor Plan

A generalized model of the differences encountered between ground floor and upper floor plans as they vary by building type (Figures 7 and 8) demonstrates how the demand for space, relative to its cost, determines the internal configurations of building interior space. In the model of typical ground floor occupance in a representative central city area, several forms of compromise are manifested. The narrow shops exhibit the principle that success in the market place is dependent on having some exposure to the passing trade; once attracted enough to enter a store, the customer may be directed to merchandise at the rear. Various devices are, in fact, employed to gain full utilization of such narrow, inherently awkward shapes.

The larger stores are those which practice some form of commodity combining (as a department store). Their need is for a large amount of space whose cost is covered by the greater volume of business which results from greater variety and general scale economies. Banks are in a similar situation but traditionally occupy such quarters for prestige purposes and the inherent trust associated with large size.

The hotel lobby is an interesting variant in that it has need for only enough frontage to provide an entrance. The space required for the lobby and registration services can be provided on lower cost space away from the street. In such instances, the hotel customarily rents narrow shop space to help defray costs.

The principles demonstrated here operate more or less independently of building type. The division of interior space is more strongly affected by its rental cost than by its form of construction. At ground floor levels, interior space of both frameless and framed structures is commonly subdivided in accordance with use needs. Varying construction methods are employed to allow this to occur. For instance, the density of columns (in a framed building) may be higher for upper floors than for the ground floor. To do this, it is necessary to distribute the weight of the upper floors on to a heavy spandrel beam between the ground floor and the second floor.

For upper floors, for virtually all uses except department stores, there is a strong correspondence between type of construction and room configuration. A typical interior arrangement of three major types is indicated in Figure 8.

The steel/concrete-framed building with heavy cladding, built in such great numbers (especially in the U.S.) between 1890 and 1940, commonly had office spaces subdivided by placing partitions along the alignment of columns and beams. Rooms, commonly, were from 4 to 7 m on a side (both length and width). The familiar view from the hallway was one of a series of evenly spaced entrance doors (often with frosted glass windows). This subdivision into small, individual offices was in keeping with the high demand for general office space in the era before the advent of giant corporations. In instances where suites of offices were required, it was common practice for a firm to rent a series of adjacent offices. Connections were made internally and but a single entrance was selected as the main one; a common sight is to see arrows on the other entrances directing the visitor.

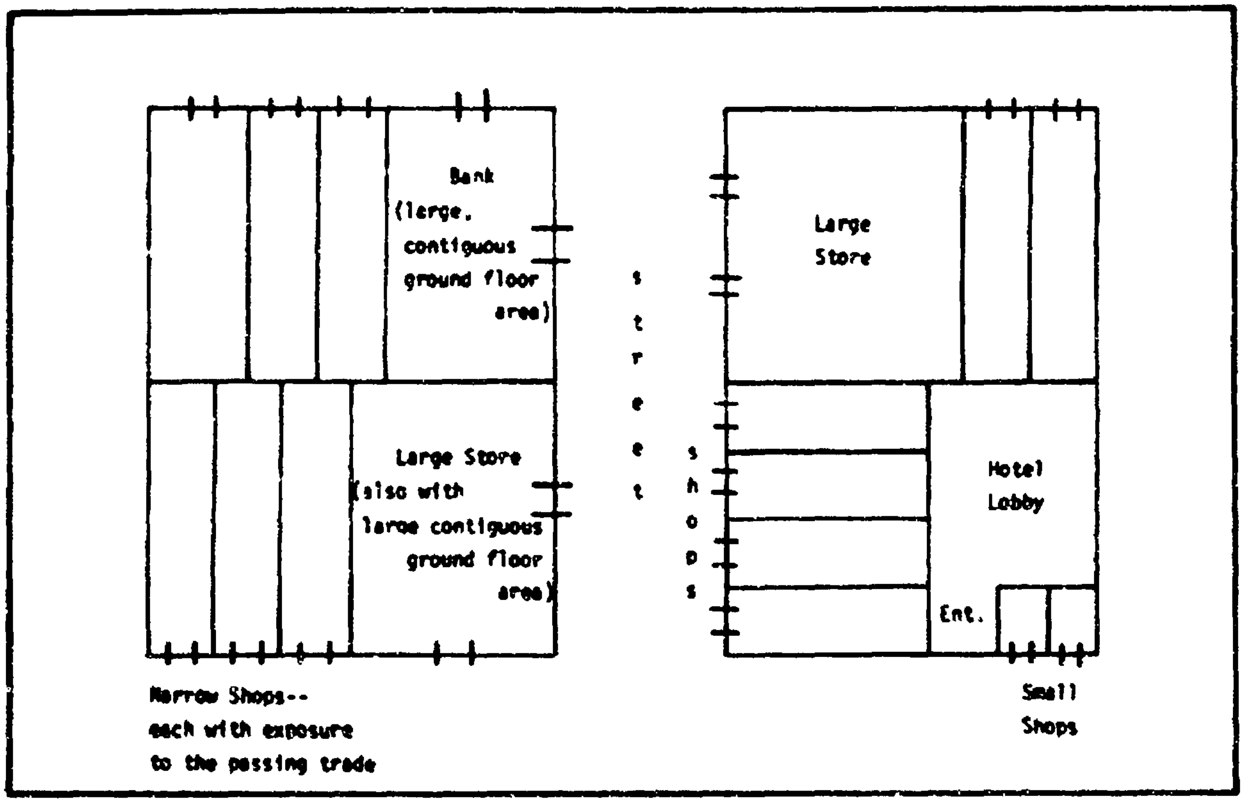


Figure 7. Typical Ground-Floor Occupance
Central City Blocks

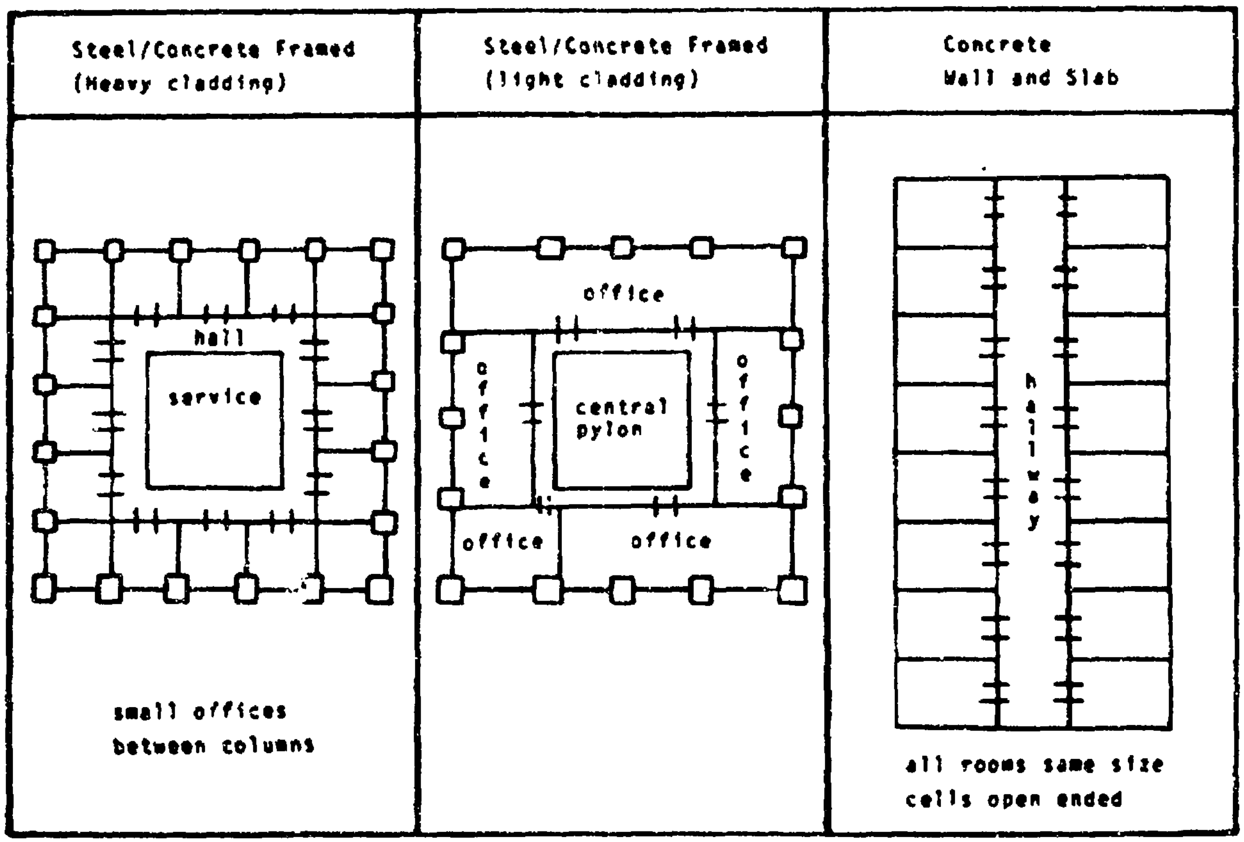


Figure 8. Second-Story Floor Plans

Coincident with the introduction of light cladding (roughly following World War II, although prototypes were in Europe in the 1920's and 1930's), was the rapid growth in the size of corporations to the point where they occupied all or much of specially built structures. An early, and famous example is the Lever House in New York City begun in 1949. An accompanying change in the philosophy of office arrangement from individual offices to open bays, with but modest space separation, also occurred. These factors interacted with the larger size of individual offices possible with the use of reinforced concrete beams which allowed open bays to be as wide as 12 m for the entire length and width of the building.

The case of the binding restrictions on interior space arrangements of the concrete wall and slab building has been noted previously. These structures have little applicability for office use and virtually none for retail stores, industries, or storage. They are most commonly used for hotels and apartments.

The influence of architectural factors on building interiors is illustrated in detail in Figures 4, 9, 10, and 11. In Figure 9, the office arrangement in the old heavy-cladded buildings and the new open style light-cladded structures is contrasted. Even the placement of office desks in the latter is meant to convey the feeling of unstructured open space. Some partitions are necessary, however, as seen in the case of presence of rooms for conferences and such office functions as duplicating or data processing.

Total areas must also be taken into consideration when evaluating interior space layout (see Figure 10). Considering that the attempt in designing a building is to provide natural light to every office, the common architectural solution for large buildings is the provision either of wings, enclosed courtyards, or smaller light wells. In this example, the service module in the center connects matching halves of the building. Articulation hallways bisect matching rows of offices, the inner of which receives light from open courtyards. The concealment possibilities of these interior spaces are significant in a military context. Their presence, however, may be inferred from astute observation from the outside. Individual office sizes are near the standard of 4 by 6 m (24 m^2): with their ceilings of 3 m, they have a volume of 72 m^3.

The theme of access to natural light is followed in more detail in Figure 4. The hallways, in both cases, since they have a lower priority for natural light, occupy the interior areas. The more fully inhabited areas enjoy the natural light. The inherent darkness of these hallways could pose a serious problem in a combat situation.

The placement of service modules also has a role to play in interior space configuration (Figure 11). For efficiency these are commonly placed in the center of the building. They may be doubled (or have several multiples in extraordinarily large structures) to serve rectangularly shaped buildings. Whatever their placement, interior arrangement is affected. Some recent design has placed elevators in shafts on the exterior of buildings as a safety precaution in the event of earthquake or fire which could seal off interior elevators and stairways.

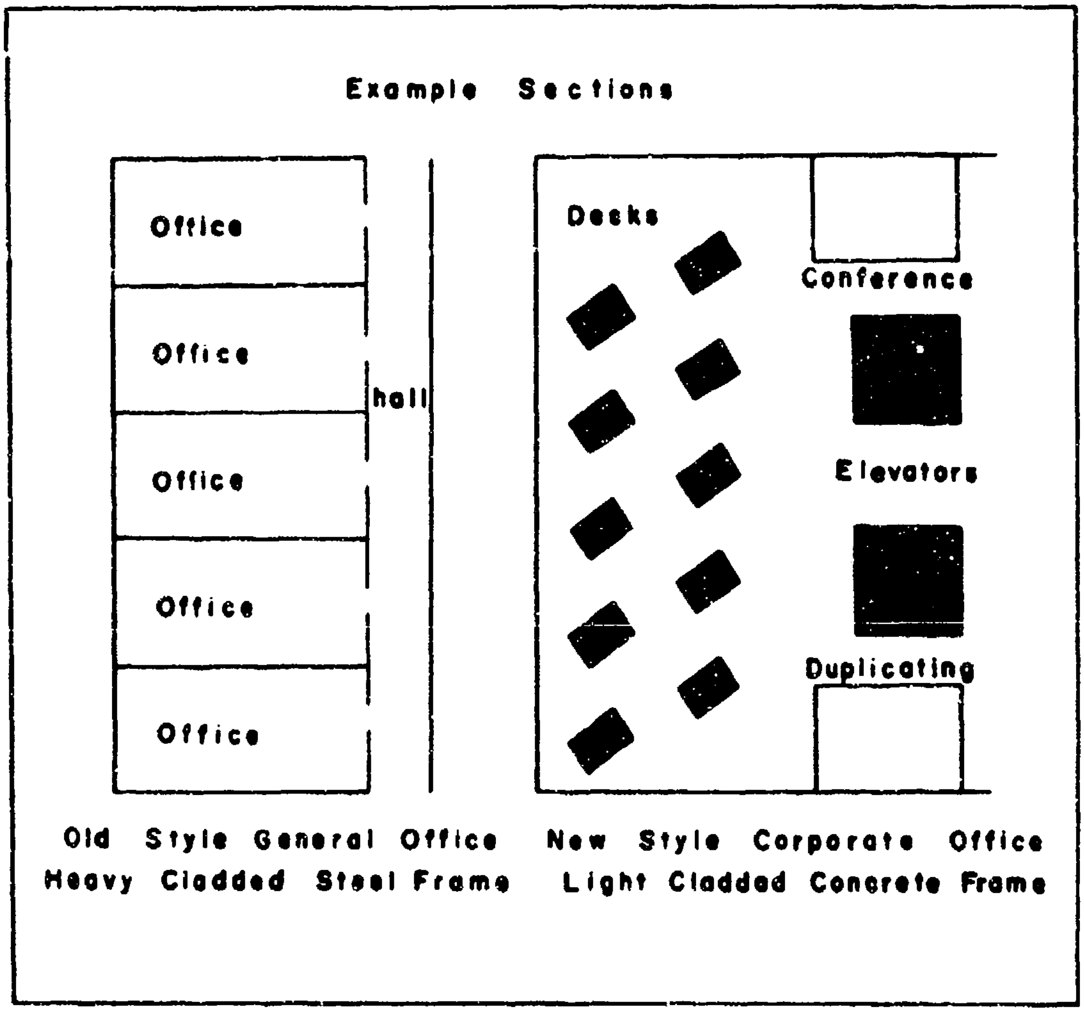


Figure 9. Architectural Factors Affecting Size and Configuration of Building Interiors Current Style of Design

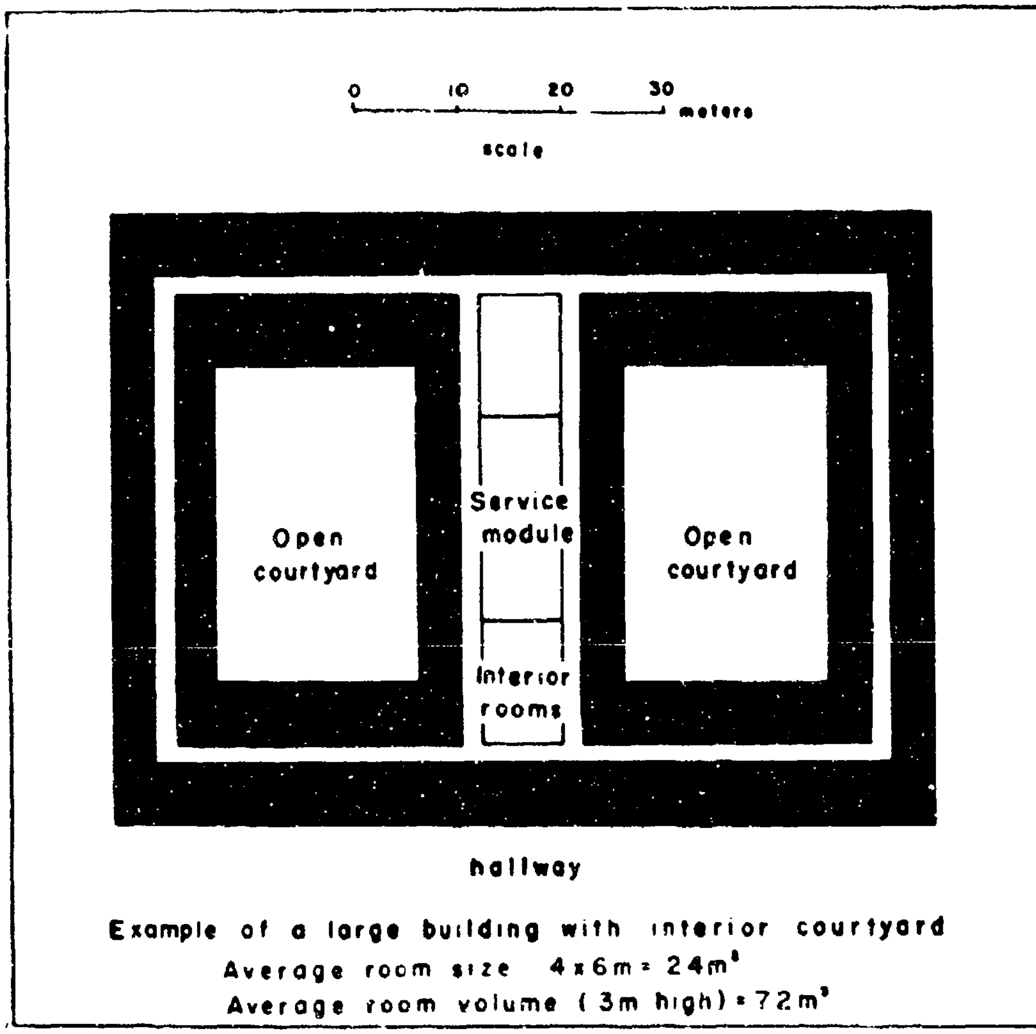


Figure 10. Architectural Factors Affecting Size and Configuration of Building Interiors Total Area of Building

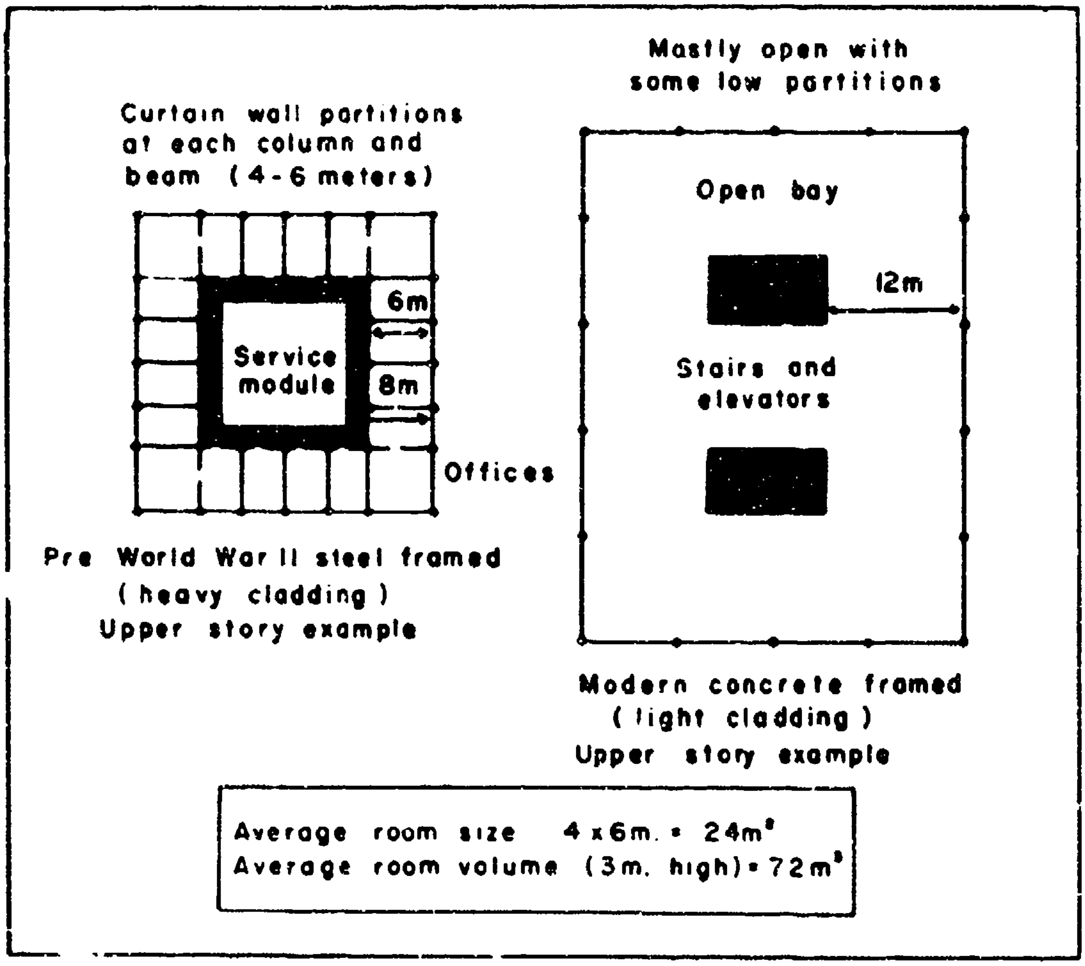


Figure 11. Architectural Factors Affecting Size and Configuration of Building Interiors
Beams in Framed Buildings
Distance Between Columns
Service Module Location

The anatomy of a representative German reinforced-concrete-framed, light-cladded building (Figure 12) demonstrates the high level of relationship which exists between the physical characteristics of the structure and how the building is used. The general arrangement is typical with the ground floor being devoted to shops, the middle section to offices, and the uppermost to building services. The building dimensions are in keeping with Joedicke's (1962, p. 54) statement that European office buildings commonly have fairly narrow rooms with partitions being about 2.5 to 3.8 m apart. He further states that two conventional methods exist for accomplishing this. In the first, the office partitions are placed along the line of all weight-bearing columns. In the second (that illustrated in Figure 12), half of the partitions are at the columns; the other half are at non-weight-bearing mullions. They follow a standard German module of 3.66 m between the mullions. These German standards all carry DIN numbers (translated as German Industrial Standards).

The ground-floor retail shops are separated from one another by partitions placed at the structural columns whose centers are 7.32 m apart. Wide windows for display purposes are at the ground level.

Office size is rigidly prescribed in Germany. According to a scale (Joedicke, 1962, pp. 14-21), the following average areas are prescribed, in accordance with the level of occupance. For a single office, 9 m^2 is allowed, 14 m^2 for a double, 15.2 m^2 for three, and 18.6 m^2 for four. The windows in the example suggest that the offices (with a width of 3.66 m) have depths of four or more meters and are thus, in accordance with the formula, designed for two, three, or four occupants. Note that the windows are placed between the supporting columns and not the mullions in accordance with a method referred to as "in-filled." The use of spandrels in between, plus the beams, gives the building a typical "banded" look. The type is very common in Europe and elsewhere.

3.2.3 Room Sizes, Detailed

Fortunately, for the purposes of this study, detailed specifications on room sizes for particular functions are widely published. Architects, cost accountants, and developers are keenly aware of the needs for space for various purposes, their costs, and acceptable minimums. Prescribed room size per function is, in turn, intertwined with design specifications for all other related items such as furniture, office equipment, window and door sizes, and modules of wall panels and carpets.

Two general levels of interior space size prevail: (1) the large, unpartitioned open space associated with the functions of general public use such as an institution or department store, and (2) that of manufacturing and storage. The latter two also have standards but areas are generally so large that they hold little importance to discussion here. The data on the smaller rooms, those used for offices of various types and rooms used for functions of human habitation, are the more significant for the purposes of this report.

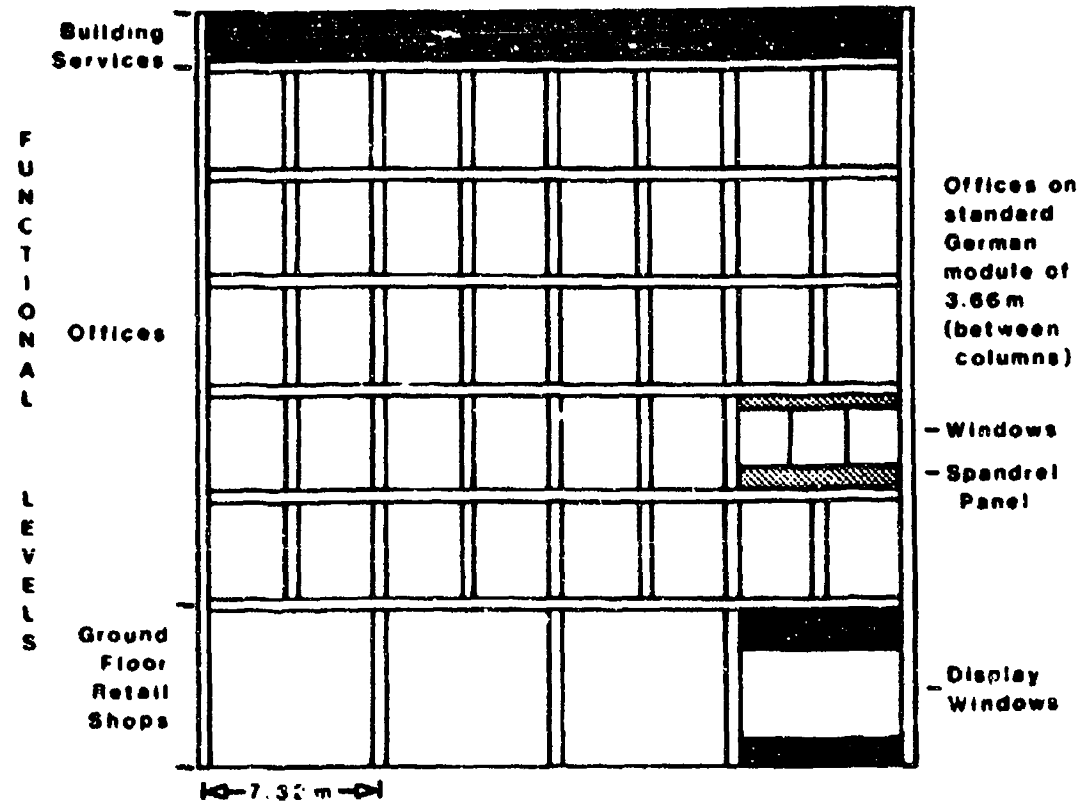


Figure 12. Typical Morphological/Functional Arrangement
Modern Concrete-Framed, Light-Cladded Building
Located in a Commercial District

The results of studying a wide number of cases (reported on in Table 2) report average areas for hotels, apartments, and offices. DiChiara's purpose in conducting the study of 40 U.S. hotels (with an average of 200 rooms and an average height of 10 stories) was to provide guidelines for new designs. Hotel developers are keenly interested in matching design to need and thus to building the most cost-effective amount of space. The success of the major hotel chains is widely known and readily followed. Hotel management accounting knows precisely the service and maintenance costs per area and matches these to anticipated revenue. Because of this high level of calculation, there is little deviation from the norm in modern construction. For recent buildings and for future construction there will be a high degree of reliability in inferring interior dimensions just by observing salient features of the exterior. To some degree, of course, the sizes indicated in the table are a result of current life styles and modes of transportation.

Table 2. Average Room Sizes by Function

International Samples

Room Type	Area (m^2)
Hotel Guest Room (U.S.)*	23.2
Hotel Lobby	102.2
Hotel Lounge	55.7
Hotel Rental Stores	223.0
Hotel Dining Room	139.4
Hotel Kitchen	102.2
Hotel Coffee Shop	74.3
Hotel Offices	13.9
Apartment Room**	17.2
U.S. Offices	
U.S. Private General	18.6
U.S. Semiprivate	25.5
U.S. Dental	11.1
Sample European Offices	21.2

*Source: DiChiara, 1973 (40 hotels studied)
**Source: Arregar, 1967 (1861 European apartment rooms in study)

Economic practicality is also the rationale for the existence of specific dimensions on offices. Business concerns know precisely how much space is required for each function. Government agencies have institutionalized the process by formula. The General Services Administration of the U.S. government even issues guidelines for office sizes depending on GS rank and duties.

For instance, GS 12 and 13 ranks are allowed 150 ft^2 if they are in supervisory positions, 100 if they are in nonsupervisorial positions. GS 14s and 15s in supervisory positions are allowed 225 ft^2 while their nonsupervisor fellows of same rank are allowed but 150 ft^2. The super ranks of 16, 17, and 18 are all allowed 300 ft^2.

Room sizes within apartments are similarly specified (see example study in Table 3). The table indicates how rooms of different functions vary in accordance with the total size (and thus cost) of the apartment. In Europe, where apartment dwelling is the mode for the majority of the urban population, large apartments are fairly common and are designed, as the table implies, for families with children as well as for singles and couples.

Table 3. Floor Areas by Function of Room
Twenty-two Apartments: International Survey

	Type of Apartment					
Type of Room	1 rm	2 rm	3 rm	4 rm	5 rm	Avg.
Living Room	-	19.2	19.7	18.0	29.1	21.5
Dining Room	6.1	9.0	10.4	14.1	14.7	10.9
Parent's Bedroom	-	14.7	15.2	16.5	15.9	15.6
Children's Bedroom	-	-	11.5	13.1	12.8	12.5
Kitchen	3.3	5.7	7.4	8.1	8.1	6.5
Bathroom	3.8	3.8	3.8	4.4	4.2	4.0
Corridors	3.3	5.6	9.5	12.5	13.6	8.9
Avg. Living Area (incl. corridors)	25.8	42.7	61.9	81.3	96.0	61.5

3.3 BUILDING VENTING

Throughout this study the point is made that the characteristics of a building are the product of its type of construction and its function. The interaction of these two factors is nowhere more obviously demonstrated than in the nature of a building's venting, that is, in the dimensions and placement patterns of windows and doors.

Examining first the influences of morphology, the statement may be made that the constructional form of a building limits the architect in his placement of windows.

Frameless structures, those depending on the exterior wall to carry the bearing loads of the building, impose the most stringent restrictions on windows, due to the fact that any opening or disturbance of the wall reduces its structural integrity; the strongest wall would be one with no windows or doors at all.

Brick buildings, as the most common example of the frameless form of construction, manifest their limitations on windows in three distinctive ways. (A knowledge of these provides a set of revealing keys for the field identification of these buildings.) First, the proportion of the building facade devoted to windows and doors must be kept small. On an average of 15 international buildings measured (Table 4), the proportion of glazing (not counting the minor amount of space taken up by the casing) is only about one-fourth of the total facade of a building (25.8 percent). Larger and smaller areas of window relate to style choices, and in the case of fairly large percentages (in the thirties), it was undoubtedly necessary to provide some sort of extra structural support.

The second characteristic is that the windows in such structures must be kept vertically aligned. In this way the loss of structural integrity is only along the vertical alignment of the windows while the intervening space of solid brick is given the task of carrying most of the load. A further reflection of this technique of providing venting is that the windows are invariably long, narrow rectangles. Window sashes of the American form are generally vertically sliding from the middle while the European style is to have the windows hinge on each side with the two halves latching in the middle; a double set ("storm windows") is commonly used in the colder climate areas.

A clue to the problem of loss of structural integrity is commonly observable from the exterior of the building in the arching of one or two rows of brick above the window. This traditional method of load support serves to restore some of the loss created by the window.

The third characteristic venting feature of brick buildings is the lack of windows at the corner of the building. It is the corner of a mass type structure which provides a high proportion of the load-bearing strength. Some architects of frame buildings have, in fact, been criticized for not putting windows out to the corner when they could (Joedicke, 1962, p. 88). Joedicke says that frame buildings not only do not have such a need, but that the corner columns are often the least heavily loaded of all. He supports this by adding that "concentration of mass at the corners is a typical and necessary form of construction in masonry structures, in which the solid corner piers insure the rigidity of the wall."

An interesting response to this requirement is seen in European brick buildings located on street corners. To provide windows facing out on an intersection, the designers frequently allow for a corner facade of the building which lies at a 45-degree angle from the two planes of the structure (see Figure 13). With a structure of moderate size, this practice means that there can be a standard size window along this angled facade while not disturbing the structural character of brick wall on the "corners." A corner window has a far broader cone of vision (and thus field-of-fire) across the street intersection on which it faces than does a window nearest to the corner in an ordinary brick building. The view from these angled corner windows also provides much longer lines-of-sight down the streets they overlook.

Table 4. Venting of Steel/Concrete-Framed (Heavy Cladding) Buildings
Upper Floors--Stores, Offices, Hotels
International Sample

Measured Cases		Heavy Cladding		Glazing	
Number	Country	Relative Area	Percent of Total Facade	Relative Area	Percent of Total Facade
1	U.S.A.	480	58.5	340	41.5
2	U.S.A.	2,730	70.9	972	29.1
3	PHIL	2,005	48.8	2,100	51.2
4	U.S.A.	3,450	48.3	3,695	51.7
5	U.S.A.	1,220	78.2	340	21.8
6	U.S.A.	2,880	64.5	1,584	35.5
7	U.S.A.	1,070	77.5	310	22.5
8	U.S.A.	1,116	72.9	414	27.1
9	U.S.A.	735	75.4	240	24.6
10	U.S.A.	115	59.0	80	41.0
11	U.S.A.	325	54.6	270	45.4
12	U.S.A.	570	70.4	240	29.6
13	FRG	960	54.1	815	45.9
14	FRAN	496	77.9	140	22.1
15	FRG	1,306	72.9	486	27.1
16	FRAN	1,710	59.6	1,160	40.4
17	AUSTRIA	1,425	70.0	610	30.0
18	UK	668	72.3	256	27.7
Average			62.3		37.7

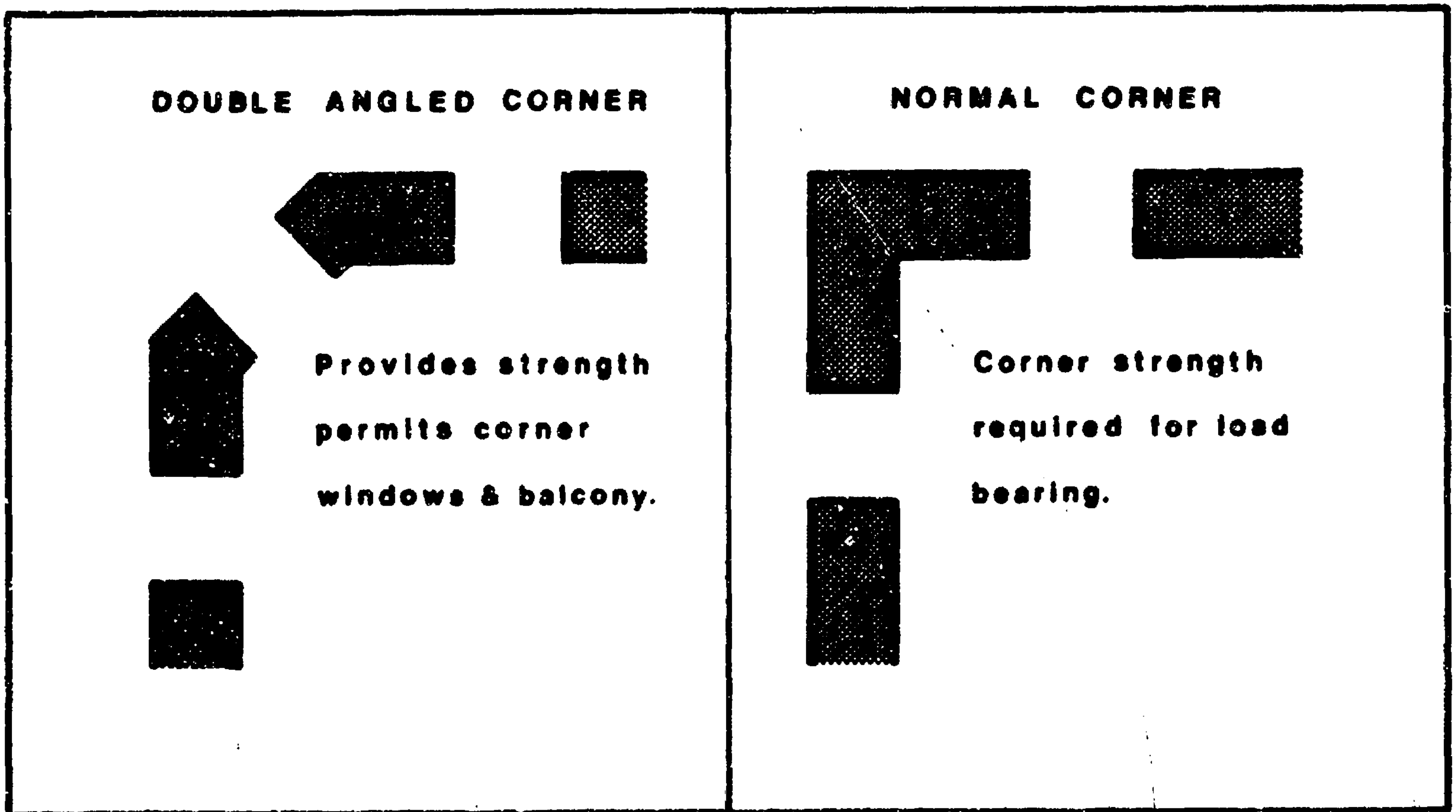


Figure 13. Corner Window Configurations of Masonry Buildings

The venting placement of other types of mass construction buildings is less restricted by structural requirements. For the wall and slab structures, the venting is commonly the entire exterior wall of the individual cell. Since these walls provide the only possibility of gaining natural light into the room, they are frequently composed mostly of glass. If, as is often true with apartments, there is a balcony, a glass door (sliding or hinged) is also present. Since this exterior wall is not load-bearing at all, structural strength is in no way impaired. Tilt-up buildings traditionally have few windows. The principal form of openings is large doors for handling bulk goods. If the buildings are used for retail stores, an open glass front is expected. Those used for offices will have some windows but still the principles of maintenance of structural integrity are observed.

Commentators in the architectural literature frequently express dismay that the exterior style of buildings, including the form of venting, built with steel or concrete frames took such a long time after their introduction to stray from the traditional forms associated with masonry buildings. The use of heavy cladding (usually brick) on these framed buildings continued from their earliest days in the 1890's until construction temporarily ceased with the onset of World War II. Windows, too, were placed in between the columns often in a manner quite similar to masonry buildings. The first departure from the traditional was in response to functions which required more natural light, such as industries and department stores on upper floors. The breakthrough architecturally, though, came in Germany in the 1920's following the Bauhaus school of architecture led by Walter Gropius. These ventures into light cladding, so common throughout the world today, are attributed especially to the period from 1924 (marking the end of inflation in Germany) and 1930 (the coming of the depression and the Nazis). These modern styles were criticized by the Nazis (Lane, 1968) as being socialistic: their answer was a return to traditional (and thus more rural) forms of architecture. The wide acceptance of this traditional style may, in fact, be responsible for the continuation of the pitched roof for much new urban construction today.

Interestingly, many of these light-cladded buildings constructed in Germany in the 1920's look little different than ones being erected today. The Schocken department store, built in Chemnits (now Karl MarkStadt in GDR) in 1928 has broad bands of continuous windows at each floor separated by horizontal bands of marble-finished spandrels. An apartment development built for Siemens Electric Company in 1929 has a high proportion of glass in its walls.

The most important feature of framed buildings, relative to venting, is that since the frame is providing all the structural strength to the building, there is no restriction at all on the kind and manner of venting such a building can have. The amount of venting can range all the way from 100 percent glass to no glass.

Function has some role to play in dictating the amount of venting. For reasons of preserving privacy and for easier insulation, concrete-framed apartment buildings will ordinarily have fairly large windows for living rooms, smaller ones for bedrooms. Other buildings, designed to house equipment

rather than people (a telephone central control building, for example) may elect to have no windows in which case the outer cladding is opaque but not load-bearing.

3.3.1 Function versus Form

A whole host of relationships governing amount and style of venting revolve around the interaction of the shape of the building and its intended function. Several principles may be set forth. The application of these to real-world situations in cities could be of great importance to military planning. A knowledge of what to expect in a city by knowing in advance the kinds and locations of the various existing functions could be of great value.

Of paramount importance in the development of a knowledge of the relationship of function and form to venting is recognition of the fact that in all commercial areas of a city there is a striking difference in both morphology and function between the street-level floors and the upper floors. At street level, the requirement for exposure to the passing trade means that street floors in these commercial areas are virtually all used for commercial purposes, primarily the purveying of retail goods and services. As part of this exposure comes the universal use of large windows. They are used in part to display the merchandise while serving as an open invitation for the customer to enter the establishment. The concept goes back to the bazaar whose open stalls permit the potential customer to examine the merchandise. Windowless fronts, by contrast, repel potential customers.

In the commercial centers ("downtowns" or central business districts) of all cities, the street-floor frontages are made almost entirely of either windows or doors. This phenomenon continues along major arterials leading out of the downtown until a point is reached where the street does not carry a sufficient number of potential customers to warrant commercial land usage. The pattern reappears in neighborhood shopping areas, miniature commercial areas in their own right. Stores in modern, outlying shopping centers duplicate the conditions of the downtown.

The reality of this phenomenon should be considered by military planners because of its implication that relatively little wall breaching might be required along commercial streets. Measurements of the areas in cities where the phenomonon exists would be useful for military planning.

Figures 14, 15, and 16 serve to illustrate how function, within buildings of the same type of construction, has a bearing on window number and placement. Figures 14 and 15 together show three separate types of functions all using steel/concrete-framed, heavy-cladded buildings (1890's to 1940's vintage).

All three exhibit the use of the ground floor for commercial purposes. The street-level space in the hotel and the office building is divided into small shops and leased out. Certain affinity uses are associated such as travel agents and florists in hotel buildings and magazine and lunch counters

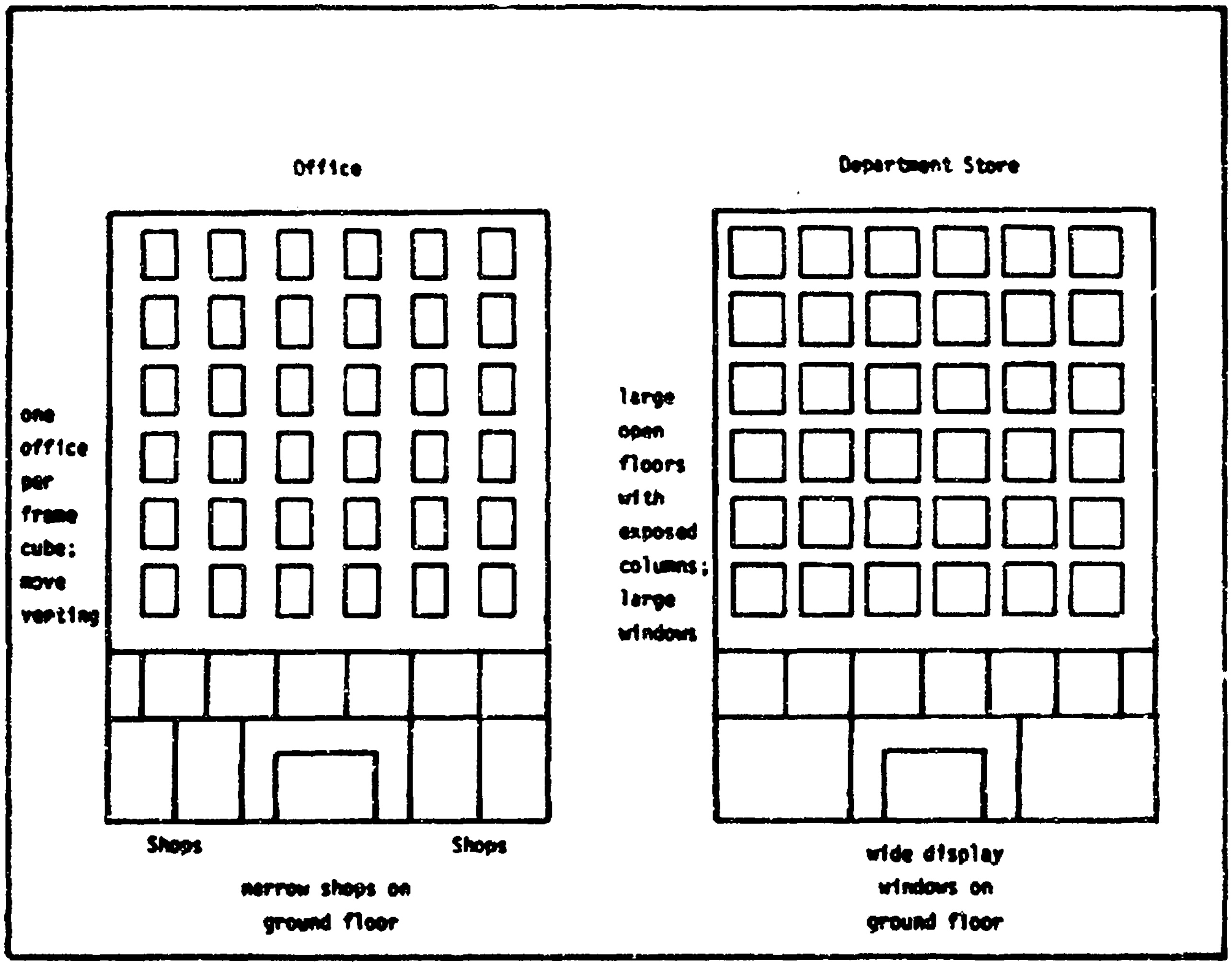


Figure 14. Effect of Building Function on Venting

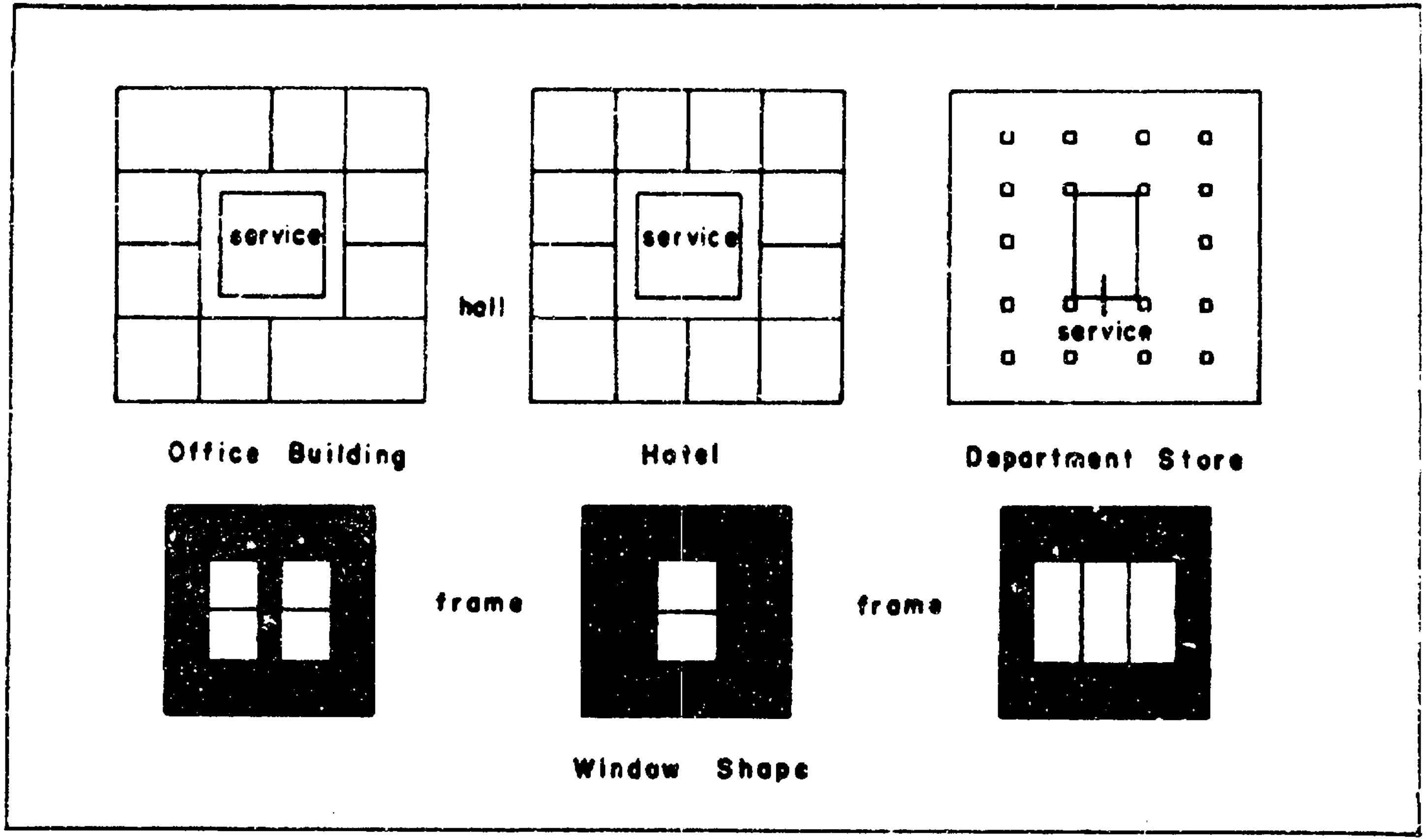


Figure 15. Use Factors Affecting Size and Configuration of Building Interiors

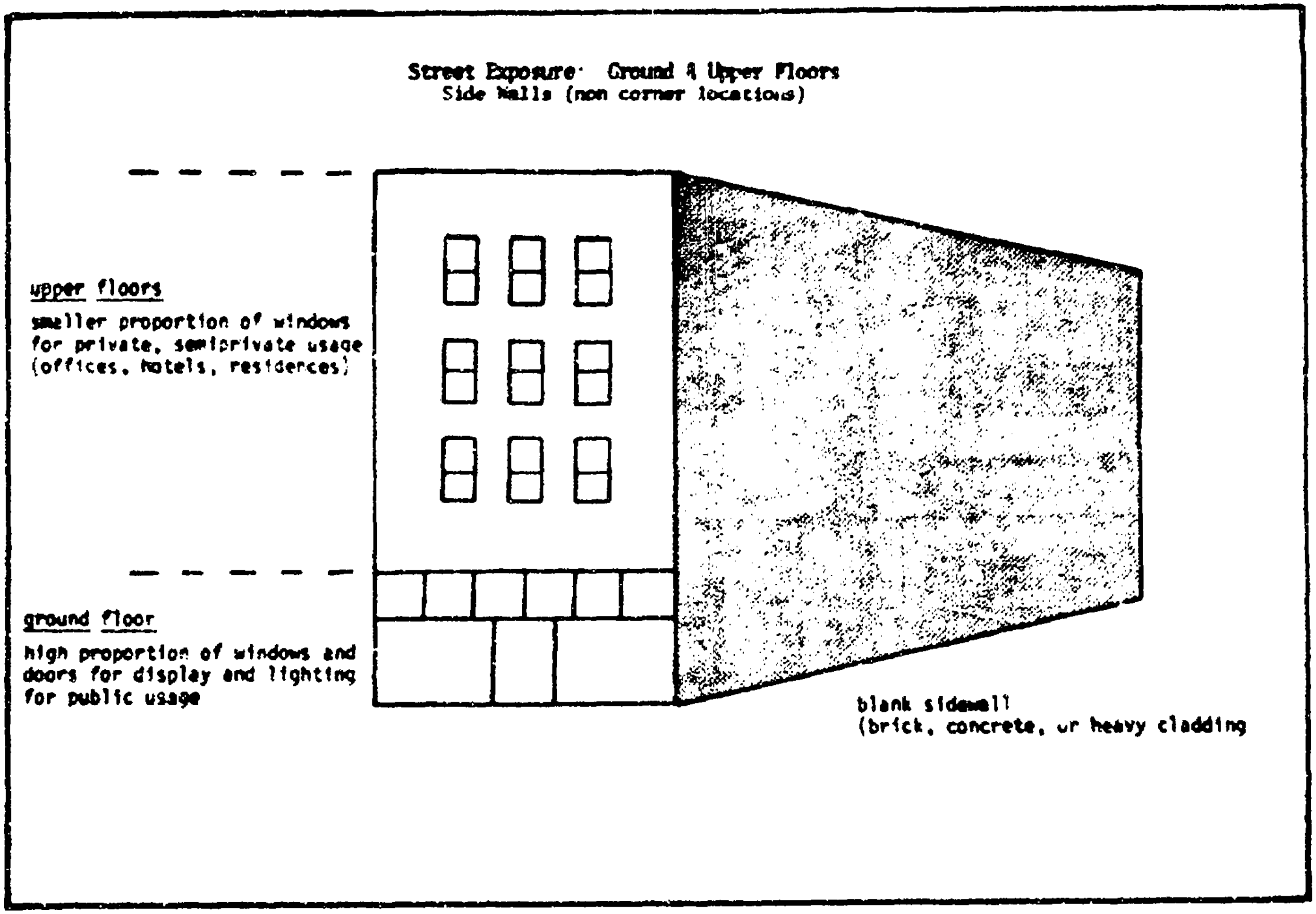


Figure 16. Building Venting

in office buildings. The department store utilizes the ground floor to the fullest for displaying and advertising wares available throughout its multi-floored space. Note that in all three cases, the ground floor is taller than any of the other floors. The need for high ceilings is seen in some cases, such as occupance by a commercial bank office on the ground floor. Department stores must offer a sense of spaciousness in their ground-floor space (on which they place a premium). Mezzanine floors or partial floors are often found. The possible utility of mezzanines for military usage poses some interesting questions. They are at a height above the ground floor great enough to scan the streets below and yet they do not follow the same requirements for exits which defenders of floors above face; far more space is at their disposal for retreating if their defensive position were to become untenable.

The venting arrangement for the floors above, explained on the diagrams in Figures 14, 15, and 16, clearly demonstrates a direct relationship with functional need. The guest room of the hotel, in these older structures, typically has but a single window for light and ventilation. The excessive light and noise in traditional downtown hotels from larger windows was avoided in the design.

Offices, on the other hand, sought more light for their workers and frequently had two or three window units per each office, located as they were between beams and columns of the frame. Excessive light created temperature problems in warm summer areas. The customary old solution was the provision of canvas awnings; today, single-room air conditioners are often seen jutting out from these windows.

The department store, with its extraordinarily large windows on every floor, manifests the same commercial notions that a merchandising concern should display its wares to the market place regardless of the height above the street. Interestingly, in later years, these large upper windows were blanked out by painting them or covering them with drapes. Modern department store planning emphasizes interior design and has few exterior display windows, even on the ground floor. The term "window shopping" could become lost from the vocabulary.

The relationship between windows and interior floor space for these three types is seen in more detail in Figure 15. For the office building, there is a pair of windows between each column (on each floor). Penetration of these windows by arms fire from the outside may be only into a single office or may, as with one of the larger corner offices in the diagram, involve more space. In the case of the hotel, there is but one window per structural cell. In the case of heavy cladding, the form of partition is reasonably resistant (as covered in detail in Chapter 4.0). The numerous larger windows of the department store provide access to large open spaces.

The theme of venting and function continues in Figure 16 but with the addition of the introduction of the possible military problems posed by the building's blank sidewall. Virtually all buildings along a city street have windowless sidewalls as they are designed to be placed against an immediately adjacent building. Their exposure, upon the razing or destruction by arms of

the adjacent building, brings to bear the problem of wall breaching. If the building in question is constructed of bricks, there is the problem (see Chapter 4.0) of the lower floors of multistory buildings being quite thick. Even if the structure is steel- or concrete-framed, this hidden outer wall is usually made of reinforced concrete at least 10 cm in thickness.

3.3.2 Data on Proportional Venting per Structure Type

Tables 4, 5, 6, and 7 present data taken from measurements of photographs of 73 d rent buildings of four major types of use from cities in 13 countries. The dat. give a clear picture of the relative amounts of venting for the different types. The order is progressive in amount of venting going from the average of 25.8 percent glazing (glass windows) for the brick structures in Table 5 to the extreme cases in Table 7 where glazing forms close to half the facade (at 47.5 percent) and the light opaque cladding (itself often glass) forms the balance.

In the case of the brick buildings, any part of the nonglazed area is heavy brick wall (its thickness being a function of the story in question and the height of the building). Buildings of this sort obviously offer a high level of both concealment and protection against small arms fire.

The heavy cladding offices and hotels of Table 4 have an expected higher ratio (37.7 percent) of glazing. The nonglazed area is composed of heavy cladding (Chapter 4.0 has details) and consists of reinforced concrete, hollow tiles, and brick, Concealment and protection are still high.

Tables 6 and 7 record the differences between two of the basic methods of sheathing a modern building with light cladding materials. In the first case (Table 6), the method of "in-filling" between structural columns and beams is addressed. In such structures, the frame members are visible from the outside, and the glazing and varying forms of opaque cladding are placed in between them. The columns and beams form some 14.6 percent of the total: of course, in Table 7 the frame forms essentially the same proportion of the total and would be exposed in the event of even a modest amount of arms fire. It is most important to note that the proportion of glazing in both examples is virtually the same. The suggestion could be made that the occupants of such structures feel too exposed, almost unsafe unless there is some sort of an opaque panel extending from the floor up to about a meter in height. Office furnishings up against fully glazed walls often present an awkward situation, both visually and practically.

Table 7 examines buildings which truly qualify as having a "stretched skin" or "curtain walls." Even in these, many of the most recent buildings observed have fairly small areas of their facades glazed. These smaller windows are often a response to a desire to reduce radiation of heat from the building as energy costs go up. In others, such as in the Philippines example, smaller windows allow less of the heat and glare of the tropics to enter the building. Air conditioning efficiency is also facilitated.

Table 5. Venting of Brick (Mass Construction) Buildings
Upper Floors--Stores, Offices, Hotels
International Sample

Measured Cases		Solid Wall		Glazing	
Number	Country	Relative Area	Percent of Total Facade	Relative Area	Percent of Total Facade
1	CR	236	78.1	66	21.9
2	FRG	104	81.2	24	18.8
3	FIN	51	79.7	13	20.3
4	U.S.A.	71	78.9	19	21.1
5	U.S.A.	426	74.7	144	25.3
6	FRG	336	72.7	126	27.3
7	U.S.A.	112	60.1	72	39.9
8	NOR	223	73.4	81	26.6
9	SWED	277	81.5	63	18.5
10	U.S.A.	270	69.2	120	30.8
11	U.S.A.	127	82.5	27	17.5
12	U.S.A.	49	60.5	32	39.5
13	FRG	94	80.3	23	19.7
14	CR	32	74.4	11	25.6
15	FIN	59	61.4	37	28.6
Average			74.2		25.8

Table 6. Venting of Steel/Concrete-Framed (Light Cladding) Buildings
With Panel Infills (Frame Visible)
Upper Floors--Offices, Hotels
International Sample

Measured Cases		Structure Members Col's, mullions, beams		Opaque Cladding		Glazing	
Number	Country	Relative Area	Percent of Total Facade	Relative Area	Percent of Total Facade	Relative Area	Percent of Total Facade
1	FRG	40	23.1	45	26.0	88	50.9
2	FRG	58	19.9	91	31.2	143	48.9
3	FRG	16	17.0	42	44.7	36	38.3
4	FRG	47	28.3	42	25.3	77	46.4
5	U.S.A.	57	37.2	21	13.7	75	49.0
6	U.S.A.	164	27.5	108	18.1	324	54.4
7	CR	315	13.2	1,215	50.9	855	35.9
8	U.S.A.	426	28.3	-	-	1,080	71.7
9	U.S.A.	365	42.2	125	14.4	375	43.4
10	NOR	28	11.8	126	52.9	84	35.3
11	U.S.A.	200	4.3	2,266	48.9	2,163	46.8
12	FRG	48	13.8	156	44.8	144	41.4
13	PHIL	38	21.4	90	50.6	50	28.0
14	CAN	54	8.3	258	39.4	342	52.3
15	NOR	70	7.4	455	48.2	420	44.4
Average			14.6		38.1		47.3

Table 7. Venting Of Steel/Concrete-Framed (Light Cladding) Buildings
Curtain Wall (Frame Obscured)
Upper Floors--Offices, Hotels
International Sample

Measured Cases		Opaque Cladding		Glazing	
Number	Country	Relative Area	Percent of Total Facade	Relative Area	Percent of Total Facade
1	U.S.A.	444	78.6	121	21.4
2	U.S.A.	170	47.2	190	52.8
3	U.S.A.	238	61.3	150	38.7
4	U.S.A.	485	43.9	619	56.1
5	FRG	2,112	73.3	770	26.7
6	FRG	1,794	43.7	2,310	56.3
7	FRG	252	43.4	328	56.6
8	FRG	1,205	53.3	1,056	46.7
9	UK	560	55.5	448	45.5
10	FIN	484	38.2	784	61.8
11	DEN	666	36.0	1,184	64.0
12	FRG	820	68.6	375	31.4
13	NOR	1,925	52.4	1,750	47.5
14	CZECH	530	40.5	780	59.5
15	U.S.A.	4,030	50.1	3,875	49.9
16	FRG	450	38.5	720	61.5
17	CR	945	51.9	875	48.1
18	PHIL	105	62.5	63	37.5
19	PHIL	476	70.0	204	30.0
20	SWED	210	54.6	175	45.4
21	PHIL	171	52.9	152	47.1
22	NOR	231	54.9	190	45.1
23	PHIL	558	60.2	369	39.8
24	U.S.A.	96	66.7	48	33.3
25	U.S.A.	668	74.8	225	25.2
Average			52.5		47.5

The use of these figures on the relative amount of the facade of a building devoted to glazing should be extremely useful in development of principles and training aids for building identification in the field. Recognizing these salient features can provide important clues about the character of the interior of the structure.

The provision of absolute measurements of window size presents a difficulty because of the variation in design of particular buildings. Still, some guidance can be gained by examining the binding factors involved. One constant to be observed is that for floors above street level in a building, the height is invariably around 3 m. Given further that there is a practical limit to having windows extend downward to floor level, it may be presumed that they begin about 1 m above the floor on the average. An additional constant is that there is little advantage to having windows extend all the way to the ceiling. Doing so would not extend visual possibilities (mostly downward, anyway) and would permit the entrance of excessive heat and glare. Given these parameters, window heights on buildings of any type should not exceed between 1.5 and 2.0 m. Width of the windows is, of course, another matter. As discussed at length earlier, the width has a strong relationship with function as well as with structure for the frameless buildings. Modules of up to 1 m wide are common in many buildings. In several measurements made in Europe in 1976, window widths in brick buildings were found to be around 80 cm.

With either modules of about a meter, windows in steel/concrete-framed heavy-cladded buildings (in accordance with findings presented in Figure 15 extend from 1 m wide in hotels to 2 to 3 m in offices to the full 6 to 7 m (between structural columns) in department stores.

For the light-cladded buildings with their higher proportions of glazing, the height of windows is usually within the 1.5- to 2.0-m limitation established above; but they frequently are in a continuous banding across the building's facade and thus have no particular width.

4.0 CHARACTERISTICS OF BUILDING WALLS

While the theme developed in the previous chapter concerned itself with the binding constraints of the combination of morphology and function on the nature of a building's architecture, the physical characteristics and dimensions of a building's walls are solely a function of the mode of construction. The laws of physics concerning the basic structural support of a building have no relationship to intended function. Certain requirements of strength and support simply must be met to offset vertical and horizontal stresses.

This doesn't mean, however, that varying functions do not occupy buildings of various types. The multiplicity of functions of any particular type of construction seen in the world today is largely a matter of inertia and the fact that building are so enduring that representative examples of all types are extant in the same city. When brick buildings were the common mode, for instance, all manners of functions were placed in them; some of them remain today.

A fundamental change in the form of building construction occurred at the end of the last century when the developed nations began to construct framed instead of masonry buildings. This was largely a reaction to the rising value of land in central business districts which made the inherently low-rise brick buildings uneconomic. The continuation of that trend has resulted in the virtual elimination of masonry structures from the central city. The net effect, for military purposes, has been the creation of a city center composed of frame buildings surrounded by a ring of masonry structures.

The following series of diagrams offers details on the nature of the walls of these buildings. Masonry walls are treated first followed by the more recently built framed structures.

4.1 BRICK BUILDINGS

The use of brick as a building material has many advantages and has been widely applauded for its role in aiding even primitive societies to meet shelter and ceremonial needs. On the plus side, the technology of building with brick was simple and represents but a man-made version of gathering and piling natural stone. The mass form of construction provided rigid and enduring walls. The difficulty of providing a roof was overcome with the use of wooden rafters and joists and, more elaborately, with the arch.

When mass construction is used, the weight of the upper part of the wall must be borne by the lower part. This load, over and above that of the load of the roof and the live load, can be provided for only when the base of the wall is thicker than the upper part. In common practice (see Figures 17 and 18), a width of brick (10 cm, using U.S. standards and 12 cm for much of the rest of the world) is added for each successive floor. For buildings of only two or three floors in height, attaining the required thickness of wall is of little consequence either in the construction process or in the space required.

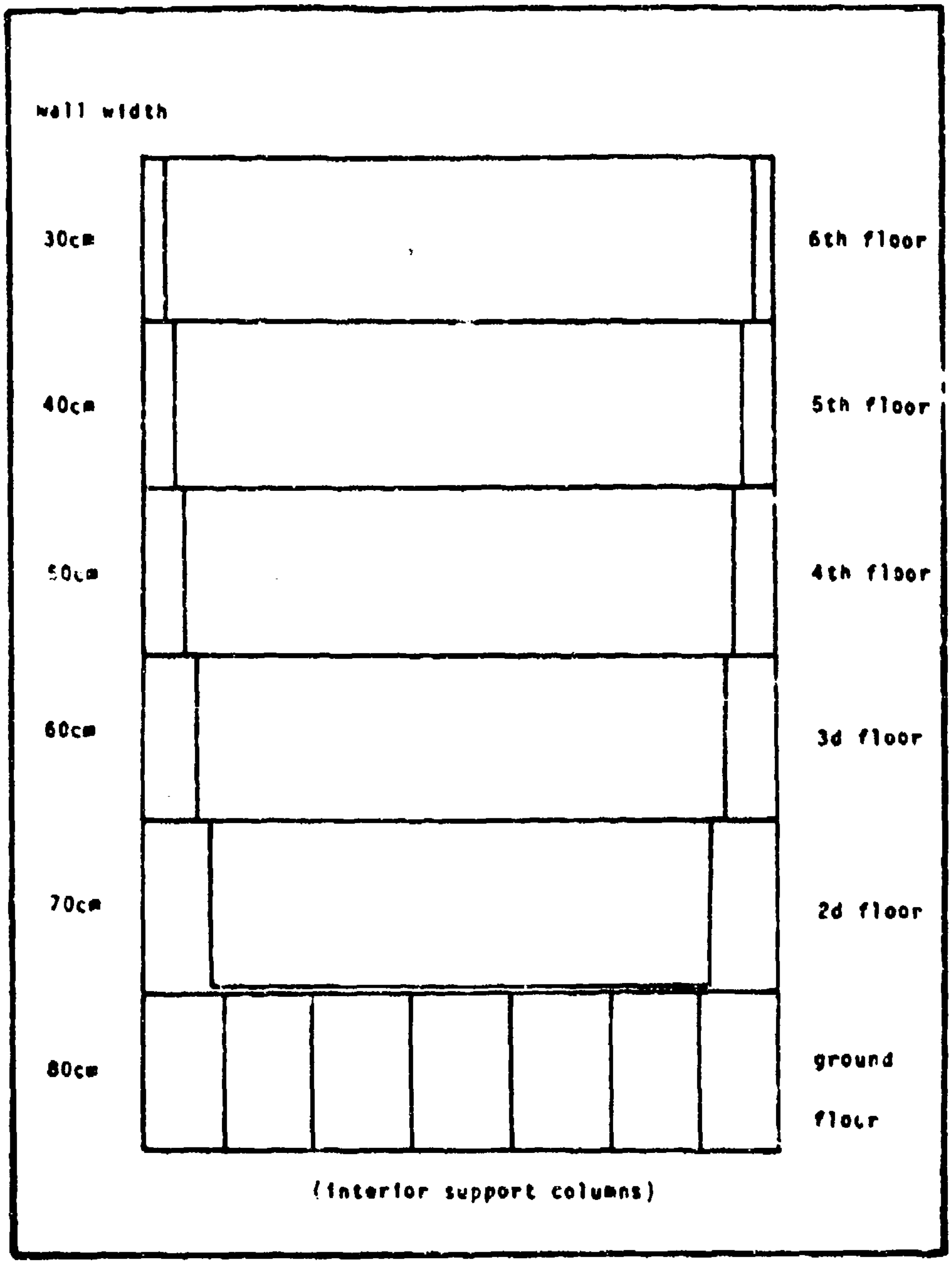


Figure 17. Typical Wall Profile
Six-Story Brick Building

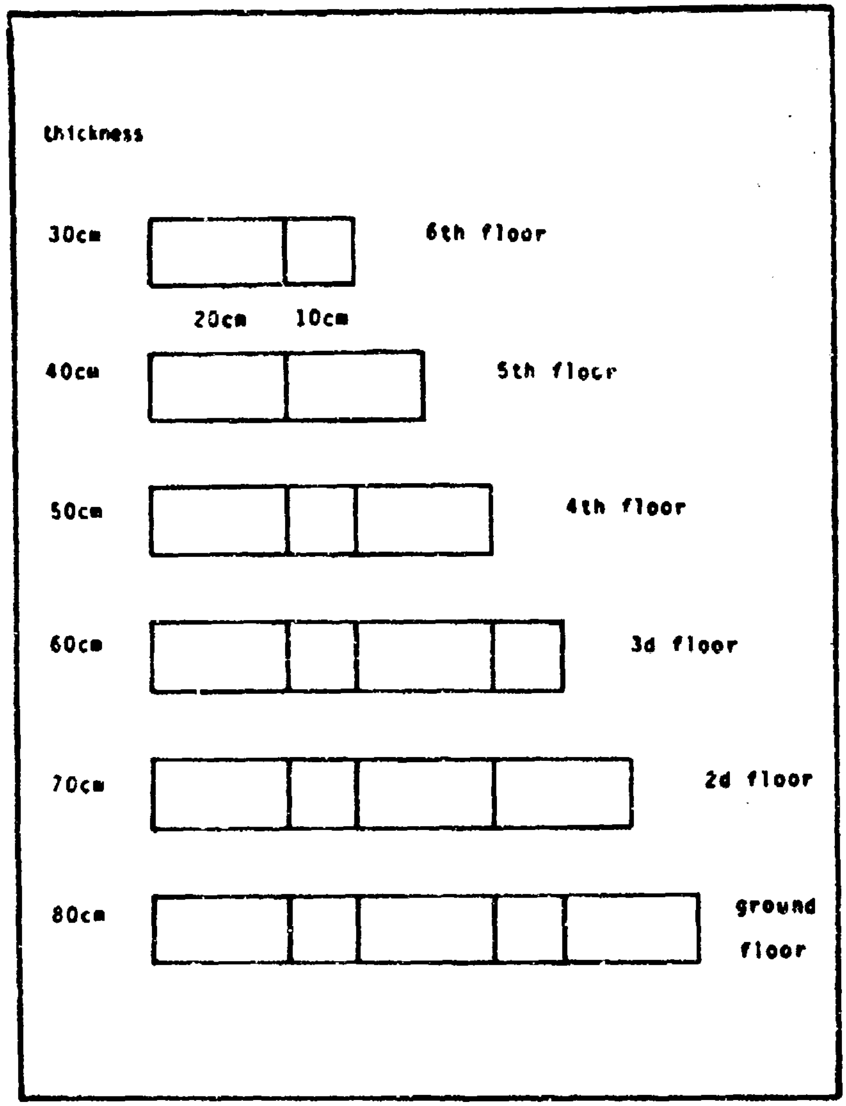


Figure 10. Prescribed Wall Thicknesses
Six-Story Brick Building
U.S. Example

In fact, one-story buildings may well be stronger than they need to be because of the need to use at least a length and a width (a stretcher and a header) of brick to achieve the desired interlocking binding.

Because of the loss of interior space which comes with increasing height, brick buildings attaining heights of 10 stories or so become impractical. In actual practice there are large numbers of brick buildings of three, four, and five stories.

Discussion of the kind of problem to be encountered at ground-floor level is instructive for purposes of military planning. Take, for example, a street in a west European city faced by brick buildings of five stories. The ground-floor wall is 80.1 cm thick (refer to Table 8). If there is no commercial land usage along the street, there will be little glazing for display window purposes. Thus, if wall breaching is necessary at ground levels, the full 80.1 cm thickness must be addressed. Even the second floor at a thickness of 70 cm presents a fairly hefty obstacle. Further consider that there are large areas of this type devoted to residential land use and that, as discussed under the heading of building venting, about 75 percent of all exterior space is solid wall. Two problems immediately become apparent. First, there is a considerable total area of wall which might have to be breached. Second, the damage caused by this breaching serves to create large volumes of rubble to serve fortification purposes.

The figure of 80.1 cm for the thickness of a five-story building in Europe has been calculated using British standards (Harrison, 1967, pp. 1-122) in which he gives figures for "bricks of standard format" as the following (for the British Standard clay brick):

Length: 8-5/8 in. (9 in. nominal) = 22.9 cm
Width: 4-1/8 in. (4-1/2 in. nominal) = 11.4 cm
Depth: 2-5/8 in. (3 in. nominal) = 7.6 cm

(The "nominal" width includes mortar of a common depth of 3/8 in. or 1 cm). Compressive strengths range from 7,000 psi for Grade B to 10,000 plus psi for Grade A. Certain engineering types go up to 20,000 psi compressive strengths.

These dimensions match measurements made on the continent but are slightly smaller than bricks commonly in use in southwest Asia which are 25 cm in length and have proportionately larger dimensions in width and depth.

New variations of traditional brick construction are being introduced in Europe and should be given some consideration even though they currently form but a very small proportion of all brick structures. These new developments are being encouraged by the brick-making industries as they attempt to compete with the variety of uses of other building materials, notably reinforced concrete.

One variant from the traditional is the hollow brick with a dimension of 22.9 by 22.9 cm and 7.6 cm in thickness. The resulting wall looks like

Table 8. Summary of Wall Thicknesses
Ranges and Averages
International Samples

Structural Character	Material Type	Height, No. Floors	Insul. Incl.	Range of Thickness (cm)	Average Thickness (cm)
Weight-Bearing Exterior	Stone	1-4	no	50.0 to 100.0 (ct)	75.0
	Brick*	1-5	no	31.8 (2 story) to 80.1 (5 story)	55.9
	r.c. Wall & Slab	5-20	yes	19.0 to 30.5	24.2
	r.c. Tilt-Up	1-2	no	14.0 to 26.7	20.4
Weight-Bearing Interior	Brick	-	no	20.3 to 34.3	27.3
	r.c. Wall & Slab	-	yes	7.0 to 15.2	11.4
Non-Weight-Bearing Exterior	Steel/r.c. Frame (Heavy Cladding)	4-50	yes	-	35.6
	Steel/r.c. Frame (Light Cladding)	2-50	yes	2.9 to 38.8	17.0
Interior Partitions	Steel/r.c. Frame (Heavy Cladding)	-	yes	-	15.2
	Steel/r.c. Frame (Light Cladding)	-	yes	6.3 to 15.2	10.8
	Brick	-	no	-	15.2
	r.c. Tilt-Up	-	yes	6.3 to 15.2	10.8

*U.S. to conventional European sizes considered

regular brick but is 22.9 cm thick and has a hollow core. Other variations come in depths of 7.6, 10.2, and 15.2 cm.

Other variations are:

Length	Width	Depth
30.5 cm	22.0 cm	7.6 cm
30.5 cm	22.0 cm	10.2 cm
34.6 cm	14.3 cm	15.2 cm

Concrete building blocks are also widely in use. The common British block length is 45.5 cm; the width, 22.9 cm. They are available in Type A (a dense aggregate material designed for use in blocks destined for the construction of load-bearing walls and with a compressive strength of 1,750 psi) and Type B (made of light-weight aggregate with a strength of 1,000 psi). Common thicknesses are 7.6, 10.2, 15.2, and 22.9 cm.

Concrete bricks (not hollow as are the concrete blocks) are also used. They have the same dimensions as the clay bricks (reported above). Compressive strengths are 1,750 psi for Class A types and 1,000 psi for Class Bs.

4.2 WALL AND SLAB BUILDINGS

The origin of the idea of using walls and floors to support each other comes from the development of "flat slab construction" (Condit, 1968, p. 243) in which the floor slab rests directly on columns and "behaves somewhat like a continuous beam." It was reasoned that since horizontal slabs acted like beams, vertical ones could act like columns. In an example of a 10-story building, cited by Condit (1968, p. 245), the floor slabs are 17.8 cm thick and the walls are 20.2 cm thick. The only true outer walls in such structures, both ends of rectangular boxes, have the same thicknesses as all the other walls. Table 9 provides data on 10 cases.

4.3 TILT-UP BUILDINGS

Tilt-up construction buildings present an interesting problem to military planners. On the one hand, with their large exterior wall surfaces with little venting, they present a large area of fairly heavy walls which might have to be breached. On the other, they may prove to have little military significance because, being a product of modern planning, they commonly form a fairly sparse pattern on the landscape and are found mostly in the outskirts of cities. With such locations, there is a greater chance that they would not be objectives themselves or bar passage to other objectives.

Their physical characteristics are fairly standard. The outer walls, although following the general notion of mass construction, are not solely responsible for supporting roof loads (plus any live loads in the case of

Table 9. Wall and Floor Thicknesses
Cast Concrete and Concrete Block
Wall and Slab Apartment Buildings
(cm)

Measured Cases		Walls		
Number	Country	Exterior (Incl. insulation)	Interiors	Floors/ Ceilings
1	UK	30.5	14.0	14.0
2	FGR	20.5	9.6	15.2
3	UK	30.5	7.0	16.5
4	FGR	20.5	15.2	19.0
5	SWITZ	21.5	12.0	16.5
6	ITAL	19.0	13.5	14.0
7	AUSTRIA	26.6	10.1	14.0
8	FGR	24.2	10.1	15.2
Total		193.3	91.5	124.4
Average		24.2	11.4	15.6

*Data Source: Diamint, 1968

two-story structures). Rather, interior columns support part of the load. Pilasters (column-like members often used to connect reinforced-concrete panels) also form part of the outer wall and share in the load-bearing function.

Wall thicknesses vary with the anticipated load. They are generally kept as thin as possible to save costs. The amount of reinforcement steel is, of course, another variable in the providing of strength. Some walls are but 14 cm thick, commonly ranging to 20.3 cm for single-story structures. The heaviest walls (those where a second-story load must be supported) reach thicknesses of 25.4 cm. For walls up to 20.3 cm thick, there is the commonly used reinforcement steel in the form of a "curtain of steel" composed of reinforcement bar ranging from 9 to 13 mm in thickness and formed into a grid with 20.3-cm centers. For thicker walls (those up to 25.4 cm), it is necessary to have two layers of reinforcement (see Figures 19 and 20) which are placed just to the inside of the outer edge of the walls.

4.4 PARTITIONS WITHIN FRAMELESS BUILDINGS

Partitions in frameless structures are non-load-bearing and are used only to subdivide interior space. Their composition and dimensions reflect the

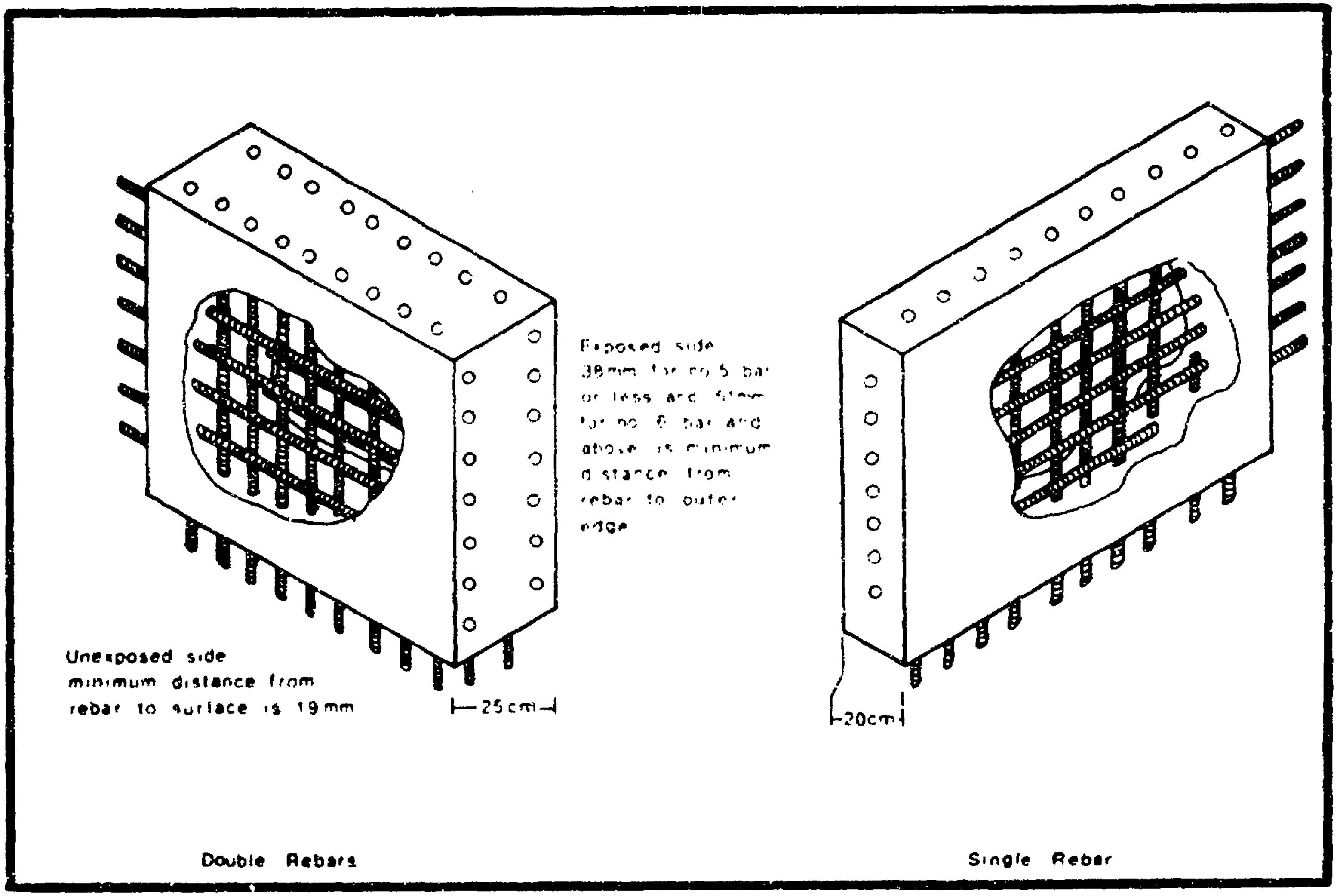


Figure 19. Examples of Double and Single Reinforced Concrete-Bearing Walls

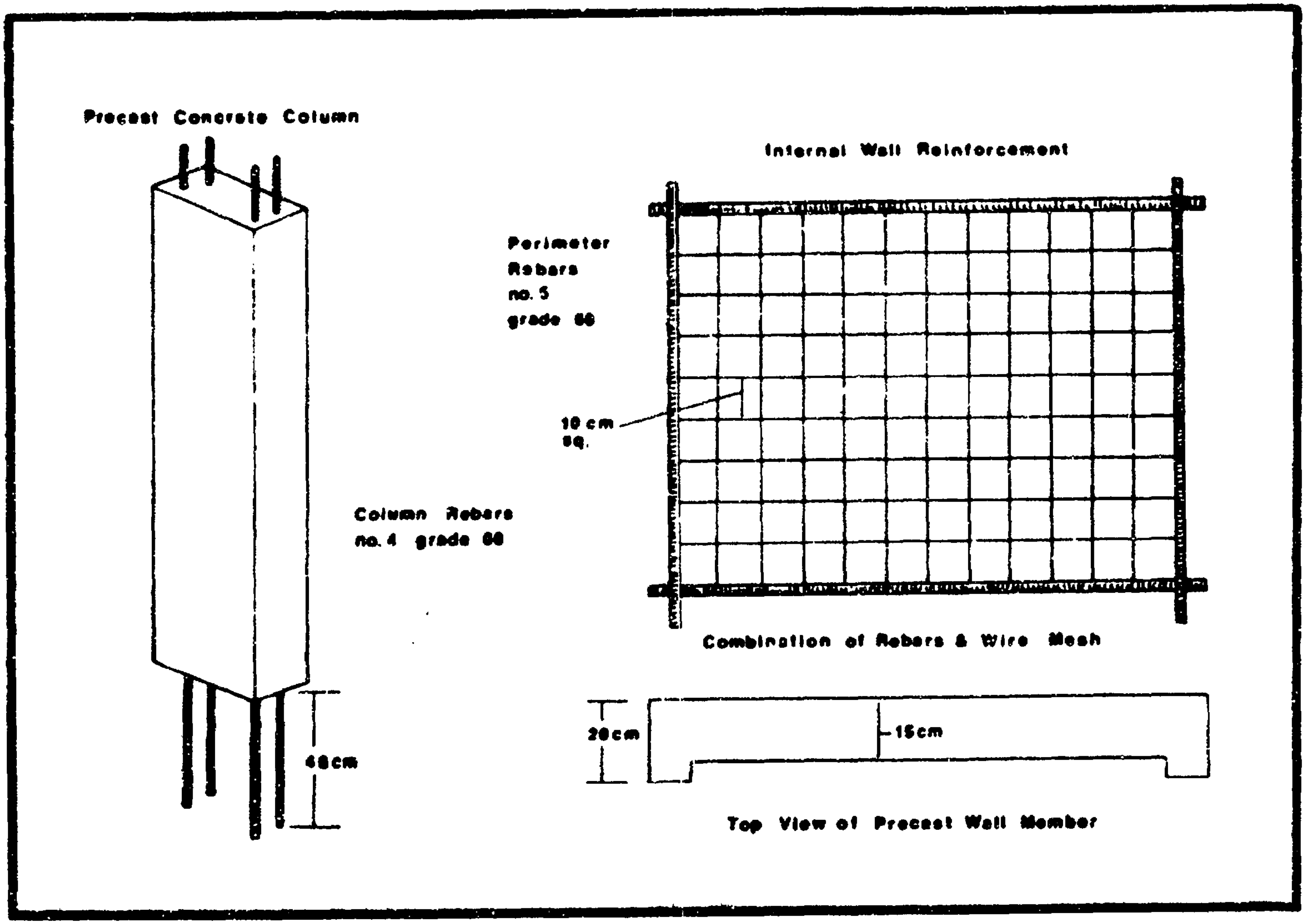


Figure 20. Example of Precast Concrete Wall and Column Units

mode of building at the time of their construction. For early brick structures lath and plaster were used. In the United States, the common practice was to place approximately 1.2 cm of plaster on top of 1.2 cm of horizontally placed wooden lath strips (separated by a few millimeters) which were nailed on to 10 cm studs. With such a treatment on both sides the total thickness was about 15 cm.

Two different types of partitions are used in modern tilt-up or concrete block buildings. If a fire-wall is required, they are made of (nominally) 10-cm studs covered by fire-resistant gypsum board and a coat of spackle and paint or veneer panel. If there is need only to separate space, as into office modules within a single establishment, they are thinner and lighter; wood paneling is commonly placed over lightweight studs.

4.5 STEEL/CONCRETE-FRAMED BUILDINGS WITH HEAVY CLADDING

It is worthwhile to recount that although framed buildings did not require anything beyond the strength of the frame to conduct all of their load-bearing functions, the use of a heavy form of cladding (often brick) persisted for four plus decades after the introduction of framed buildings in the 1890's. Part of the reason was an initial lack of boldness, not broken until Gropius and his followers introduced their "stretched skin" exteriors in the 1920's. Another frequently suggested reason is the desire not to stray from the implicit suggestion of strength posed by masonry buildings. Whittick (1974, p. 105) in commenting on the classical and Renaissance styled buildings constructed in England in the 1920's says: "If one looks at the buildings of famous architects designing in the classical/Renaissance style in the decade following the war, one would not be aware that they were built with a steel frame as the essential structural feature." Indeed, it is difficult today to make quick and certain identifications of buildings with brick facades. Clues, other than the nature of the surface material, must be sought.

More steel- and concrete-framed buildings were constructed in the 50-year period prior to World War II in European cities than might be recognized in the general descriptions of these cities which usually emphasize the low skylines and large areas of masonry buildings. Steel framing, following U.S. leadership in the field, was used first followed later by a conversion to concrete framing because of its lower possible costs. Many types of functional uses were served: department stores, factories, offices, and hotels. A few, following the German school, had light cladding but most retained the heavy cladding.

Another reason for the retaining of heavy cladding was the protection it gave to the frame. In his then contemporary book Skyscrapers, Starrett (1928) captures the mode of thinking about construction processes of the day. He presents details on the nature of the exterior cladding (see Figure 21) and states that this arrangement was required to seal the exterior of the building from the weather elements. He describes methods of brick bonding employed; in the diagram every sixth row is a row of "headers." By another method, that of "American Bonding", there is a row of headers every fourth row. Absence of these rows of headers implies a poor bonding.

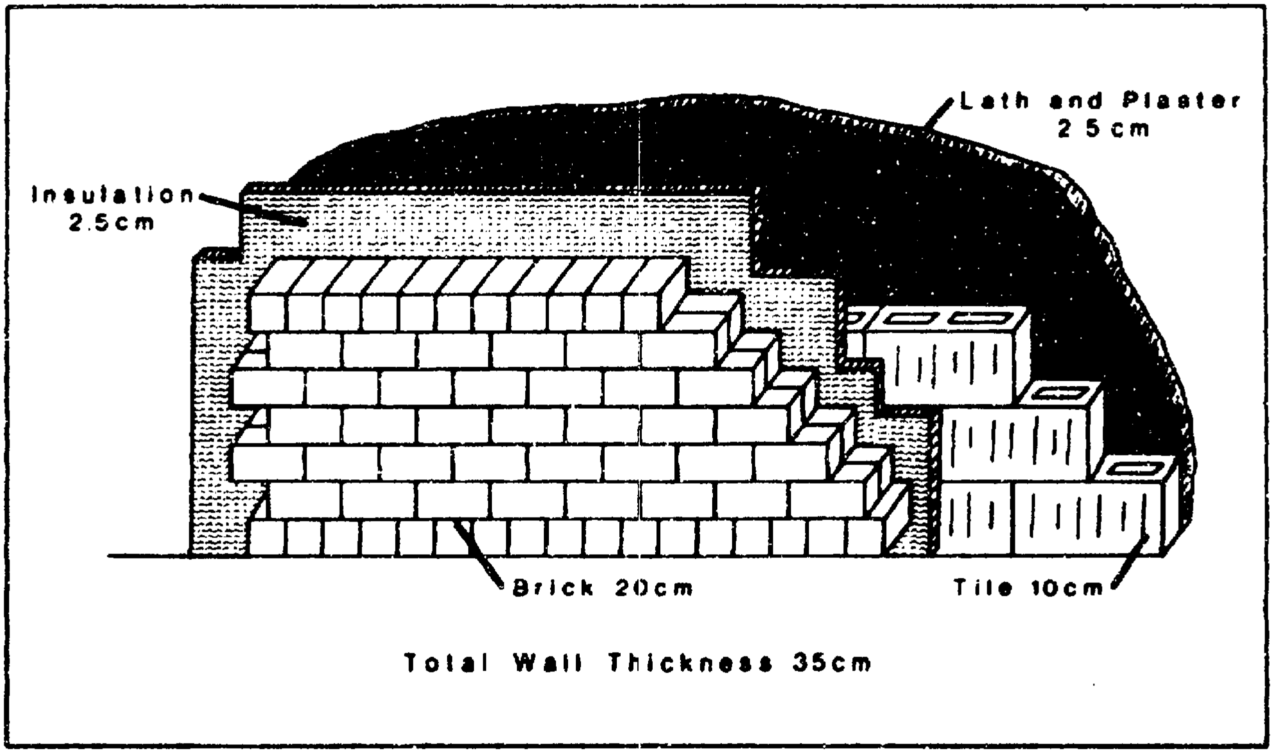


Figure 21. Typical Steel-Framed (Heavy Cladding) Exterior Wall

The total thickness of the wall in the diagram is 35 cm but there are examples of even thicker claddings. The Universal Pictures Building in New York (Hamlin, 1952, p. 445) has 46 cm of cladding composed of 30 cm of brick, a limestone veneer of 15 cm, and an interior panel of 1 cm.

Also of importance was the heavy cladding at street level where a decorative stone was used instead of the brick used in the shaft (above the pediment of the building). Starrett (1928, p. 198) states that there was often a 10- to 20-cm-thick cover of stone veneer backed by brick of another 20 cm. Interior materials added another 2 or 3 cm.

Interior partitions of these structures were also heavier than partition materials used today. Starrett (1928) states that "in the earlier days of skyscrapers, partitions were almost universally made of hollow tile, sometimes 7.6 cm thick, sometimes 10.1 cm thick. In instances where ceiling heights were as high as 5 m (as in a public meeting room, hotel lobby, etc.), partitions of a thickness of 15.2 cm were required. In addition to these basic thicknesses, there was a covering of about 5 cm of combined lath and plaster.

4.6 STEEL/CONCRETE-FRAMED BUILDINGS WITH LIGHT CLADDING

Full advantage of framed construction is taken when the exterior walls are made of light material. Not bound by the tradition of masonry construction which kept heavy cladding on framed buildings for such a long period, nearly all multistory structures erected in cities around the world in the post World War II era have used a wide variety of light cladding. The effect is that of "curtain walls" of light material. As discussed under the section on venting, such cladding may be placed in consort with visible frame members or it may be used to cover the frame. Either way the light cladding is instantly recognizable. The predominance of such buildings, plus their great heights, have allowed them to dominate the new skylines of major cities everywhere. The effect has been particularly dramatic in such places as major western European cities where these buildings contrast sharply with low-rise masonry structures. The contrast is equally strong in other traditionally low-profile cities such as Tokyo. Even New York City has had its older, already high, skyline penetrated by such edifices as the twin towers of the World Trade Center, the Seagrams Building, and the Pan American Building. Low-rise Boston is hardly visible for the large new high rises.

Once the departure from heavy cladding was made, innovation both in materials and design resulted in a wide variety of exterior walls. Certain principles obtain, however. First, as noted under "venting," these light-cladded buildings give the appearance of having glass as a very high proportion of their total facade area. The actual clear glass area though is only about one-half (refer to Tables 6 and 7) of the total; the balance is often composed of opaque glass-like material designed to blend with the glazing to give the appearance of a single, perhaps two-toned, reflective facade.

A second characteristic feature is the use of an insulation zone (containing air or some insulating material) between the outer and inner sides of

the wall. While the materials involved are ordinarily light in weight, the net effect of the several types of materials of which the wall is composed could have significance in making determinations of how they might be penetrated by arms fire of various sorts.

Three examples are shown in Figures 22, 23, and 24 of the various types of material found. The first is a fairly elaborate example (the extensive use of aluminum panels is because the building is the showpiece headquarters office of an aluminum manufacturing company). It does serve to show, though, how light materials cover insulation in a panel.

The second example (Figure 23) shows the use of double-paned glass to serve the insulation function. The elevation is an example of the obscuring of the frame by the light cladding; the effect is a "glass tower." In such instance, reflective glass is often used partly for internal reduction of glare, partly for privacy, and partly for the dramatic architectural effect created. Conjecture on the appearance of those "glass houses" in a combat situation suggests that the structure could quickly be "undressed" to its skeletal frame and look not unlike a high-rise parking garage.

Figure 24 is an example of where lightweight concrete has been used as panel material. As the material is not meant to be load-bearing, it is composed of light aggregate to keep down the weight which must be borne by the frame members. The material is still heavy enough, however, to pose a safety threat to anyone standing below during an earthquake. Thickness is also kept as low as possible (twin panels of 7 cm on each side of the insulation zone in this case).

Data on 10 examples from several countries (Table 10) serve to demonstrate the wide variety of materials used in panels on light-cladded buildings. Seven different inner wall materials and five types of outer material are used. Six different forms of insulation are employed. The relatively thin 17.0-cm average panel thickness matches the expected for such construction.

The theme of lightness is continued in interior partitions used in these buildings. The forms, however, are fairly traditional except for the substitution of new methods and materials. In Figure 25, lightweight, factory-built metal studs are used instead of the old-fashioned wooden "2 x 4s." A sheet of metal lath substitutes for the old-style wooden slats. Plastering remains conventional.

The drywall example (Figure 26) follows more traditional lines with the exception that gypsum board has replaced plaster. The use of a sound deadening board manifests the concern for sound insulation experienced when these frame structures are partitioned into a number of off   for several clients.

The summary table (Table 8) recounts all of the wall and partition types. The data are placed in rank order with the thickest walls (of their type) first. Thus, for load-bearing walls of frameless buildings, thickness ranges from an average of 75.0 cm for stone buildings, 55.9 cm for brick structures, 24.2 cm for wall and slab buildings, and 20.4 cm for those of tilt-up construction.

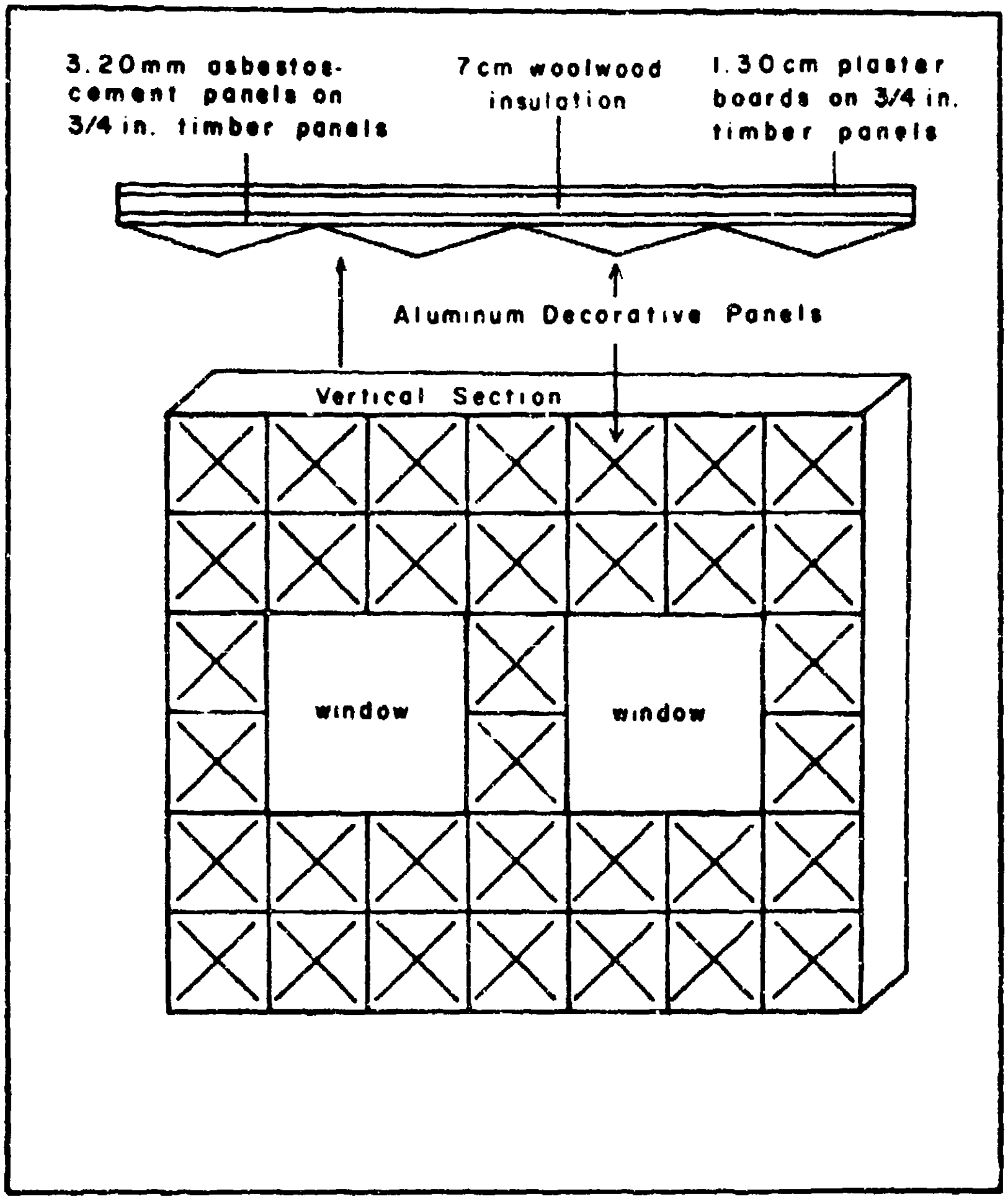


Figure 22. Fxample of a Concrete/Steel-Framed Building with Light-Cladded Curtain Walls

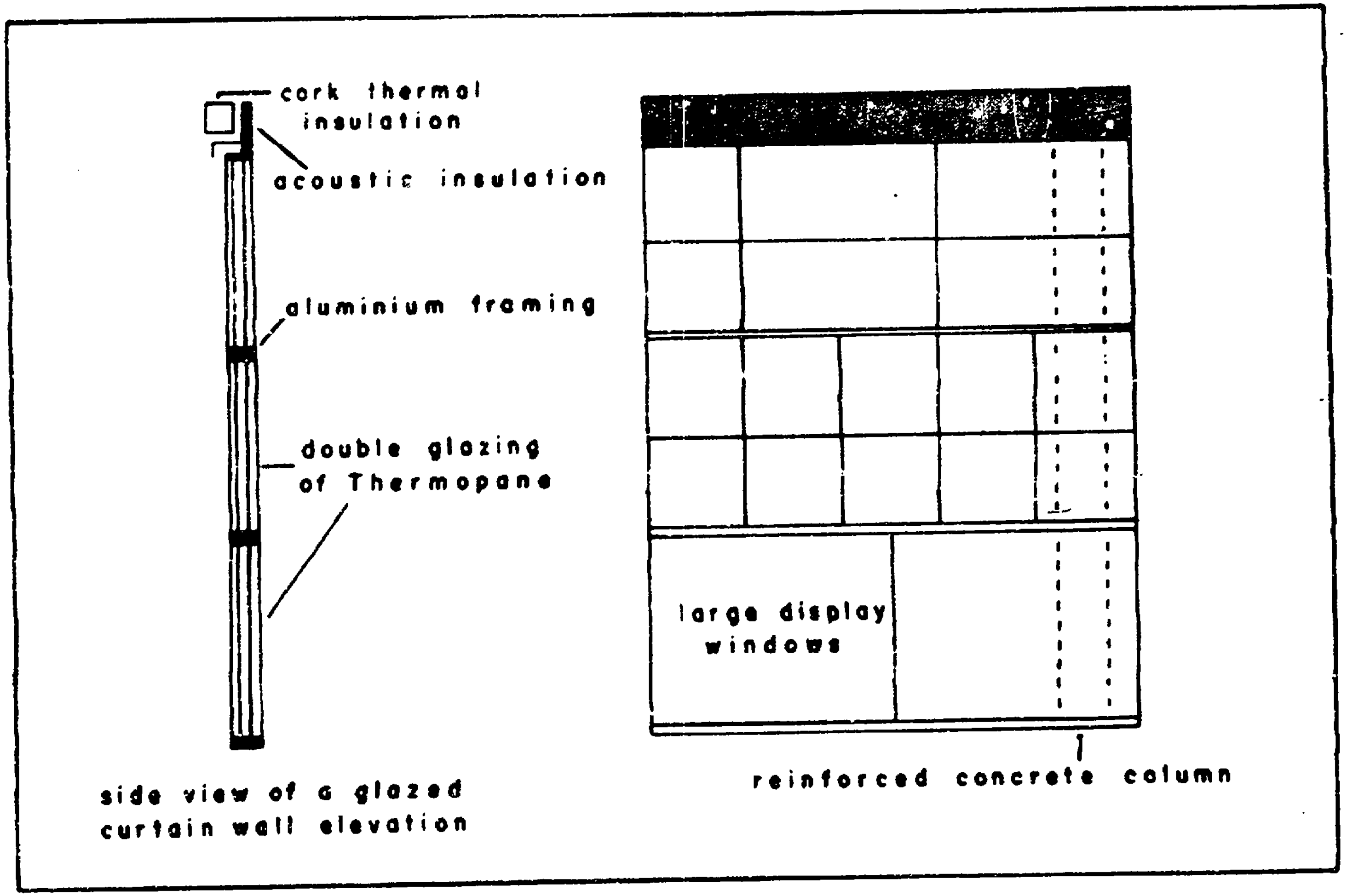


Figure 23. Glazed Elevation Framed in Aluminum

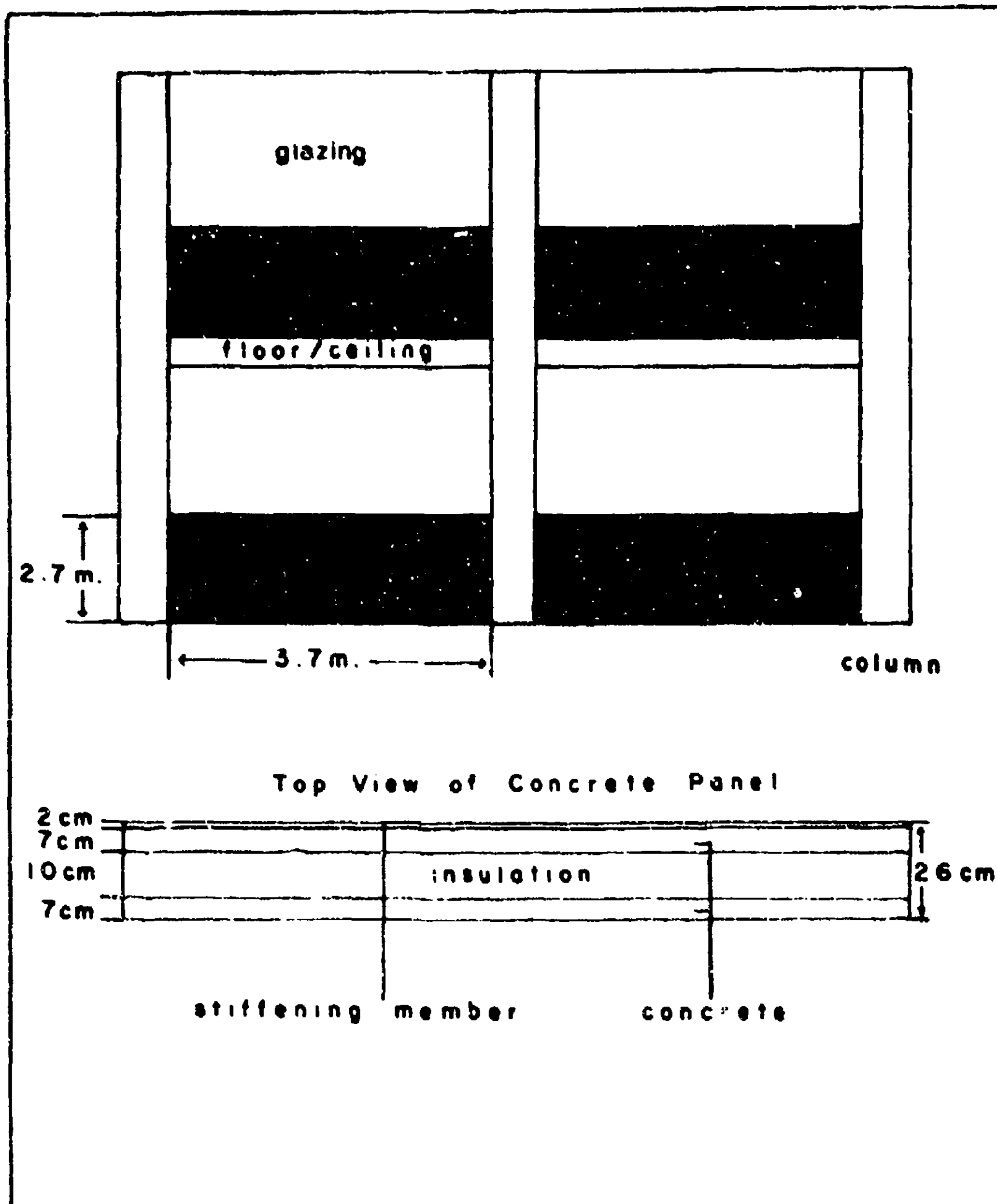


Figure 24. Two-Story Example of Concrete Panels on a Reinforced-Concrete Frame

Table 10. Exterior Panel Wall Construction
Steel- or Concrete-Framed Buildings
International Examples (cm)

Example Number	Outer Wall		Inner Wall		Insulation		Total
	Material	Thickness	Material	Thickness	Material	Thickness	Thickness*
1	aluminum	.3	foam concrete	10.0	air	23.0	33.0
2	aluminum	.3	lt. wt. concrete	10.0	glass wool	2.0	12.3
3	-	-	block	10.0	glass	4.0	14.0
4	steel	.4	steel	.4	paper	10.0	10.8
5	aluminum	.4	steel	.4	paper	38.0	38.8
6	aluminum	.6	asbestos cement	.3	fiber	2.0	2.9
7	asbestos	2.0	steel	1.0	rock wool	10.0	13.0
8	composition	1.0	composition	2.0	fiberglass	8.0	11.0
9	stone/concrete	17.0	plaster	2.0	air	1.0	20.0
10	concrete	3.8	concrete	5.5	fiberglass	5.1	14.4
Total		25.8		41.6		103.1	170.2
Average		2.6		4.2		10.3	17.0

*Glazing of the universal 6.3 mm not included.

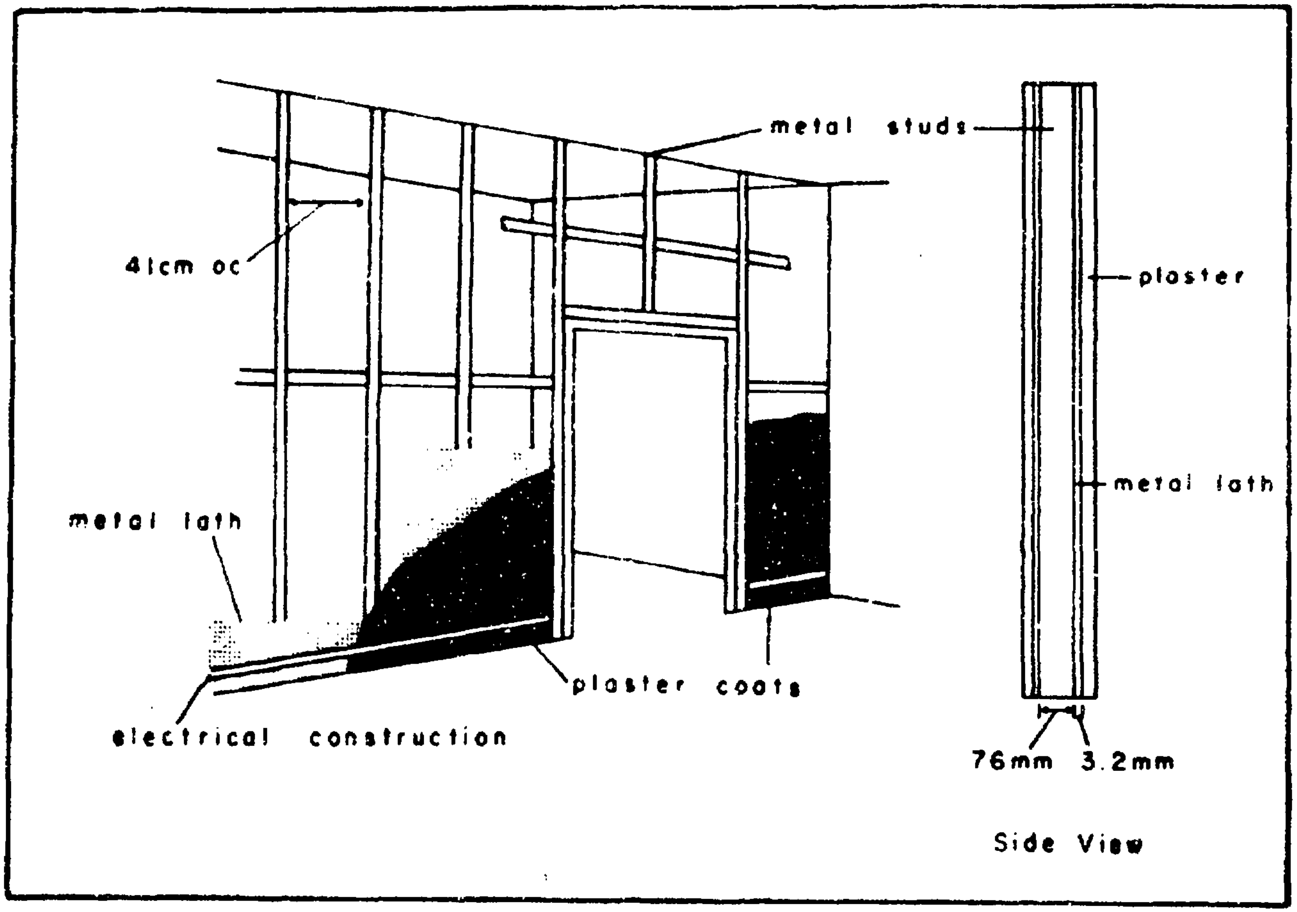


Figure 25. Example of a Metal Lath and Plaster Partition

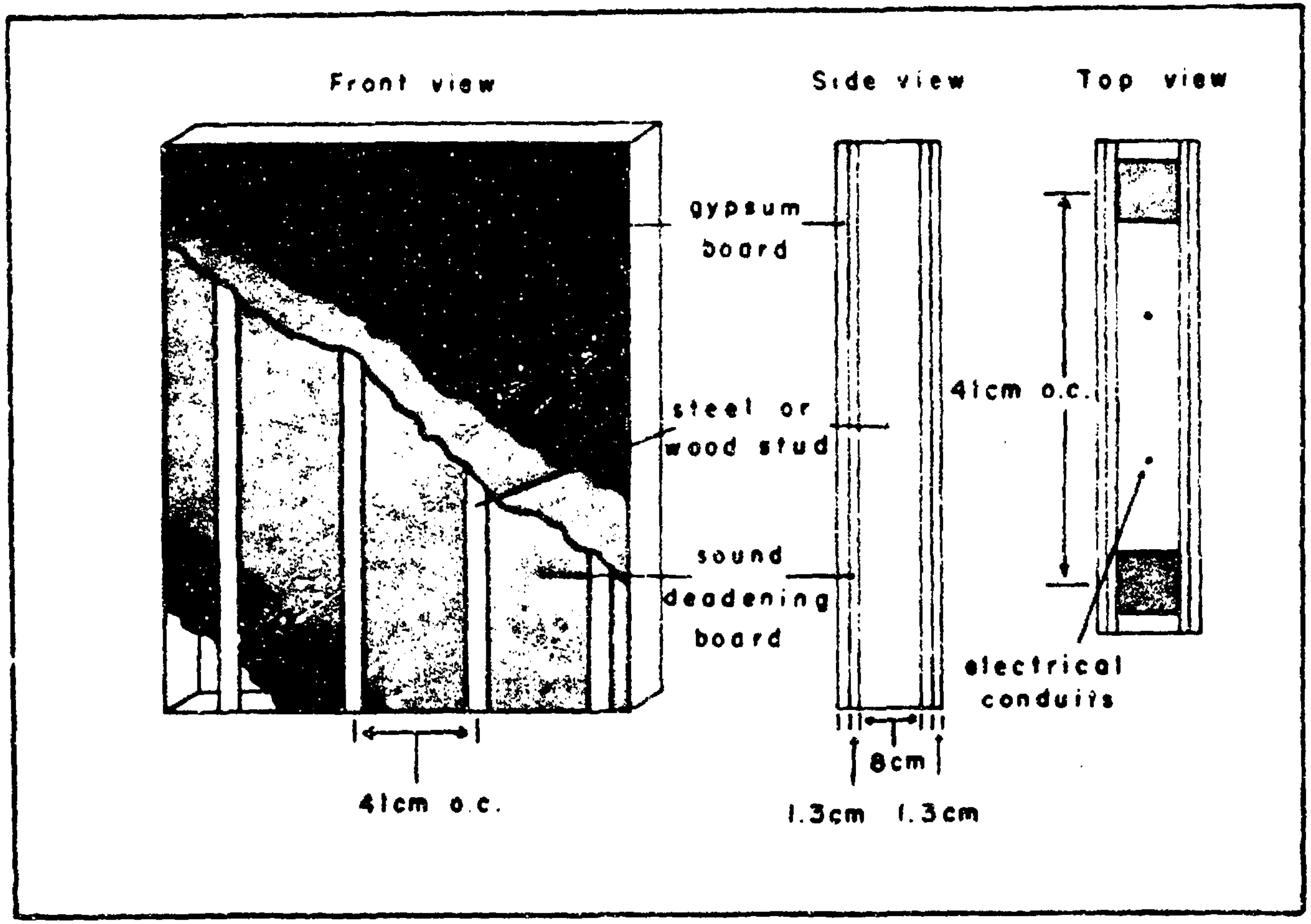


Figure 26. Example of an Interior Drywall Partition

A similar distinction is noted with the thicknesses of the heavy and light cladding of framed buildings in which the heavy types averaged 35.6 cm and the light types averaged 17.0 cm.

Interior weight-bearing walls are also given. Those shear walls found in brick buildings average 27.3 cm while those of the wall and slab structures are only 11.4 cm.

Interior partitions found in the older forms of construction--brick and heavy-cladded framed buildings--are heavier than those of the new building types of tilt-ups and light-cladded framed buildings. Thicknesses of partitions in the older types each average 15.2 cm while the later types average 10.8 cm.

5.0 URBAN SPATIAL PATTERNS

A definition of the title of the chapter requires examination and explanation of each of its component words. Urban is meant to include here all of the contiguously built-up areas of a city comprising the central city, plus all of the attached, or nearly attached, suburbs including modern concentrations of "new towns" (self-contained areas designed for residential, commercial, and industrial purposes). Spatial is used as an adjective here to indicate surface space. Patterns are those replicative of universal arrangements of land uses, building morphological characteristics, and the dynamic linkages of transportation lines which connect them with each other and the surrounding rural areas. Throughout this study (and the previous one), emphasis is placed on the universality of patterns and not upon local differences from city to city. It is even acceptable to say that there is more similarity between major cities of the world among countries of diverse economic levels than there is between a major city of a developing nation and the rural area of its own country. Accepting the notion of replicative patterns and universality is essential if sufficiently well-drawn generalizations are to be drawn for application to military planning problems.

Several universal constants obtain for cities throughout the world which favor the formation of replicative spatial patterns. It holds that if economic stimuli are universal, reactions to these stimuli will also be constant even though a minor amount of local variation can occur.

The following five constants are identified. The first states that not all the surface space of a city can be built upon. Obvious and essential non-built-upon surfaces are the streets which serve as linear linkages between functional zones and permit articulation within them and between them. In addition, there is an expressed need in cities everywhere for a certain amount of areal, rather than linear, open space components. Upon examination some of these open spaces function mostly as land designated for ceremonial purposes and as landscaped non-built-upon areas to provide spacious settings for public buildings. The landscaped grounds and public spaces in capital cities are good examples. Their appearance ranges from the landscaped areas of the Renaissance-Baroque styled Washington, DC, to paved-over Red Square in Moscow. Another major type of open space, some of which may be integral with the first, is the provision of land for recreational purposes such as parks and athletic fields.

The distinction between public-sector and private-sector space is significant. Cities with a distinctive government function or cities in countries where the importance of the state is omnipresent tend to have a higher proportion of publicly owned open space. Streets themselves are frequently wider, setbacks are broader, and there are more designated open spaces. More commercially oriented cities have narrower streets and fewer open spaces because of the greater emphasis placed on private-sector land ownership and usage. Cities of the Middle Ages were good examples of having very little land in public ownership. The planned, open style of cities built (or remodeled) during the Renaissance-Baroque period yielded a much higher percentage of

publicly owned space. Newly built sections of modern commercial cities, which have free-standing skyscrapers standing amid landscaped grounds, are a modern variant, even though the landscaped open space is privately owned.

A second constant states that the tallest buildings of a city are located at the center, in the immediate area of what is referred to as the "peak land-value intersection." From this peak of a profile "pyramid," building height decreases with increasing distance outward from the center; lesser peaks are present, however, for "outer-city" cores. A further characteristic is that building density is higher in the center of the city than elsewhere, reflecting the high value of surface space.

A third, and related, constant is that streets in the center of the city are narrower than those farther away from the city. Curb-to-curb dimensions may not be greater, depending on the nature of the original platting of the city, but the distance between buildings facing each other across the street is definitely greater away from the center because of setbacks.

The fourth constant, also related to streets, states that the significance of the center of a city requires access to and from the surrounding parts of the city and beyond, and this manifests itself in the presence of the convergence of major arterials on the center.

The fifth constant is that, in one form or another, the center of the city is the area which has the greatest concentration of cultural and governmental buildings. Government, as well as business, serves the needs of the entire populace and both require a maximum of centrality.

5.1 STREET WIDTH LINES-OF-SIGHT

Street width is obviously a readily measurable phenomenon. This measurement is also at once a measurement of across-the-street line-of-sight. The proportions of certain widths in 16 international cities (from an earlier study, Urban Building Morphology) demonstrate the universal adherence to the principles indicated above.

Data attained in the previous study are analyzed and presented in graphic and tabular form in Figures 27 and 28, and Tables 11 and 12. The pie graphs in Figure 27 provide a summary picture. The dominance (Figure 27) of streets occurring in the range of widths between 15 and 25 m is clear. The average for all cities of this class reaches nearly two-thirds (64.5 percent) of all streets (actual figures are seen in Table 11). European cities, with their heritage of narrow streets extending from Medieval times, reach a figure of 70.3 percent. Cities of the Middle East, which also and traditionally have high proportions of narrow streets (as in the medinas), attain a figure of 61.2 percent. That the figure is not higher, considering the existence of tortuous alleys associated with such places, is a product of the large areas of new planned suburban developments with their broad avenues which are averaged into city totals. Asian cities, which have the largest proportion of even narrower streets (in the 7- to 15-m width class), continue with the concept of crowded,

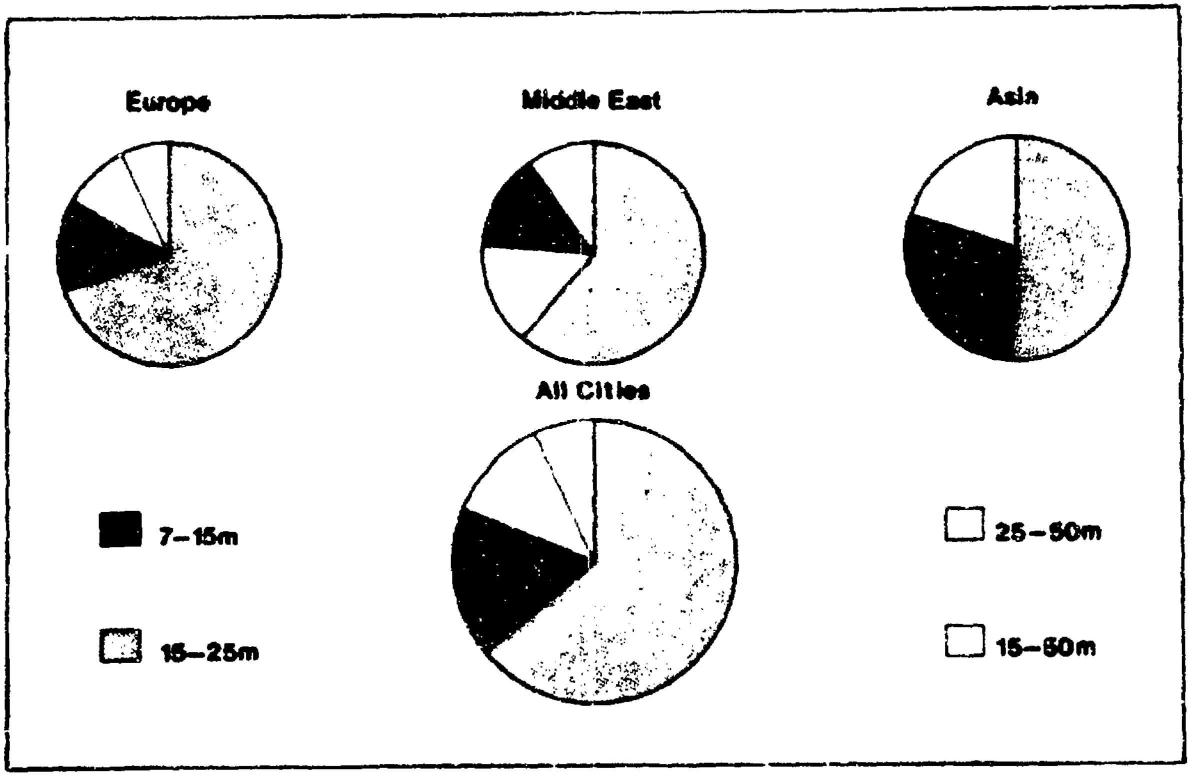


Figure 27. Lines-of-Sight Area in Each Type Summary

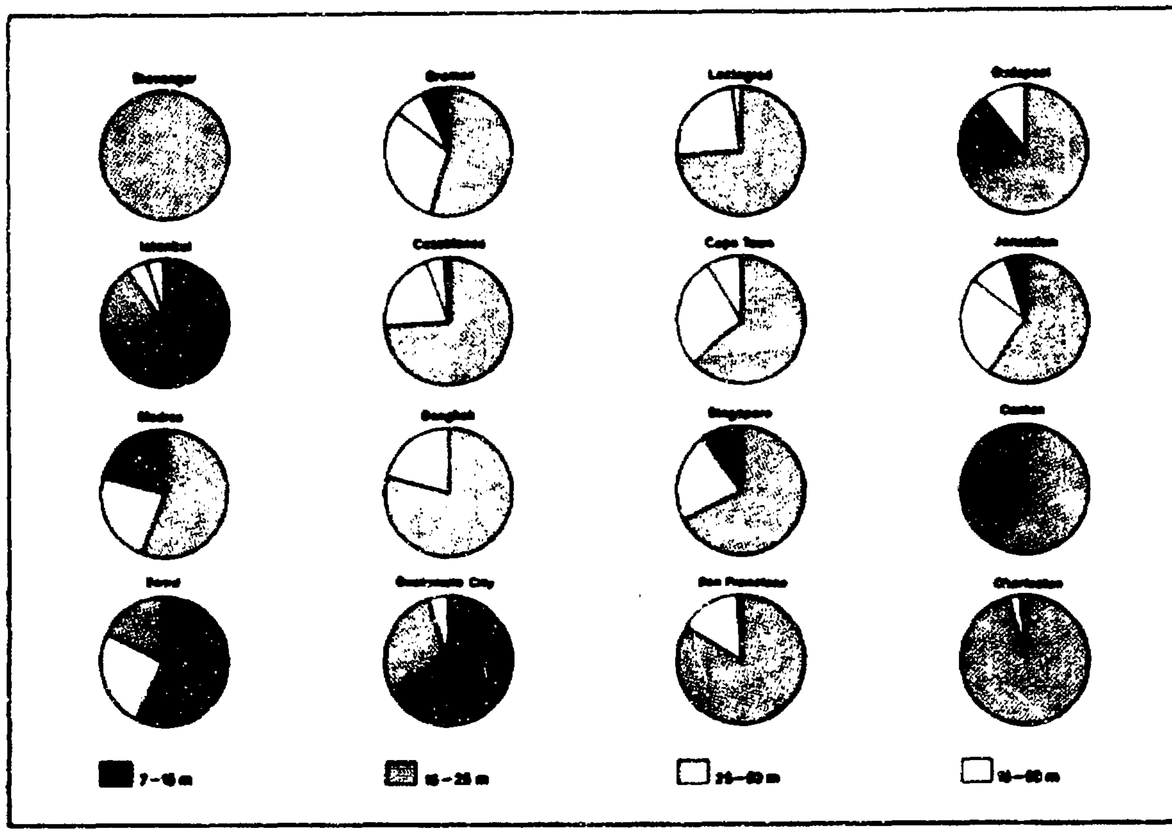


Figure 28. Lines-of-Sight Area in Sixteen International Cities

Table 11. Line-of-Sight Distribution
Regional Summary

Percentages

Region	Lines-of-Sight Type (m) 7-15	15-25	25-50	15-50	Total
EUROPE (Stav., Brem., Lenin., Buda.)	12.6	70.3	9.6	7.5	100.00
MIDDLE EAST/NORTH AFRICA (Ist., Casa., Jerus.)	14.3	61.2	15.2	9.3	100.00
ASIA (Mad., Bang., Sing., Cant., Seoul)	28.8	50.1	20.2	1.6	100.00
U.S. (S.F., Charleston)	.1	85.9	1.1	12.9	100.00
All Cities*	17.2	64.5	11.6	6.7	100.00

*Cape Town and Guatemala City included in total

Line-of-Sight Rank Order

Rank	7-15 m Region	Percent	15-25 m Region	Percent	25-50 m Region	Percent	15-20 m Region	Percent
1	Asia	28.8	U.S.	85.9	Asia	20.2	U.S.	12.9
2	Mid. East/Africa	14.3	Europe	70.3	Mid. East/Africa	15.2	Mid. East/Africa	9.3
3	Europe	12.6	Mid. East/Africa	61.2	Europe	9.6	Europe	7.5
4	U.S.	.1	Asia	50.1	U.S.	1.1	Asia	1.6

Table 12. Lines-of-Sight Distribution

Sixteen International Cities

City	Lines-of-Sight (m) 7-15	15-25	25-50	15-50	Total
Stavanger	-	2,213	2	4	2,219
Bremen	377	2,756	1,489	393	5,015
Leningrad	-	6,300	2,024	180	8,504
Budapest	4,208	14,424	-	2,156	20,788
Istanbul	1,077	254	71	77	1,479
Casablanca	48	3,820	1,032	244	5,144
Cape Town	-	1,447	214	603	2,264
Jerusalem	93	1,154	197	474	1,918
Madras	1,368	3,549	1,460	-	6,377
Bangkok	-	5,620	1,480	-	7,100
Singapore	232	1,616	514	-	2,362
Canton	1,388	1,952	-	24	3,364
Seoul	5,040	1,532	2,184	24	8,780
Guatemala City	2,294	928	-	166	3,388
San Francisco	-	10,045	156	1,796	11,997
Charleston	16	2,628	8	98	2,750
REGIONAL SUMMARY					
EUROPE	4,585	25,693	3,515	2,733	36,526
MIDDLE EAST	1,218	5,228	1,300	795	8,541
ASIA	8,028	14,269	5,638	48	27,983
ALL CITIES	16,141	60,238	10,831	6,239	93,449

narrow streets and high population and building densities. The explanation of the extraordinarily high figure for the two U.S. cities in the study--Charleston, WV, and San Francisco, CA--with streets in the 15- to 25-m category is that both of these cities are aberrancies on the American scene due largely to their physical locations in either a narrow river valley or at the end of a peninsula.

The second most significant street width is the narrow 7- to 15-m class with an aggregate for all cities of 17.2 percent. Much of the total comes from significant areas in Asian, Middle Eastern, and European cities, all of which have vestiges of patterns of extreme age comprising their total.

The third class, in rank order, is that of streets of 25 to 50 m in width (11.6 percent as seen in Table 11). Cities of the Asian region rank highest here. The explanation is that they have experienced heavy growth in their suburban areas in recent years in the form of planned, residential areas where the goal has been to alleviate the high densities associated with traditional central cities.

The smallest element is that of areas with the exceptionally broad line-of-sight distances in the range of from 15 to 50 m. These situations occur primarily in the large area "outer-city" type developments located in the urban periphery.

Detailed data for individual cities appear in Figure 28 and Table 12. Certain cities deviate quite broadly from the generalizations. Localized reasons can be cited for significant variations from regional norms. Beginning in the upper left corner of Figure 28, Stavanger, Norway, is such a small city (both in area and population) that virtually all of its streets fall into the 15- to 25-m class. The fairly large area of 25- to 50-m-wide streets in Bremen is a result of that city's extensive rebuilding following the last war. Leningrad, because it is a planned city, has no streets in the narrowest class; Budapest, reflecting its medieval character, has a fairly high proportion. Istanbul, because of its longevity as a major city of Roman, Byzantine, and Ottoman Turkish empires, expectedly has a large proportion of its total area devoted to narrow streets. Casablanca's famous Medina, with its extremely narrow alleys and byways, accounts for but a very small portion of the greater city with its extensive area of broadly set planned housing units. Cape Town, by definition, has virtually no narrow streets and instead manifests an international mode. Jerusalem's old quarter accounts for its share of narrow streets but the rest of the city is wholly modern. Madras has sizable areas of former "native quarter" settlements with narrow streets but also has a high proportion of its area devoted to wide avenues, a vestige of colonial days. Bangkok and Singapore display similar characteristics. Canton, expressing the more expected Asian pattern, has a high proportion of narrow streets. The situation in Seoul is even more pronounced. The proportion of narrow streets in Guatemala is the result of its being platted in Spanish colonial form rather than having evolved from a village setting as with the Asian cities. The high proportion of 15- to 25-m streets for the two U.S. cities is a clear expression of American standardization and an evolution and growth of cities which has occurred almost entirely in the industrial/commercial age.

All the generalizations above are supported by measurements which appear in Table 12.

5.2 INTRA-CITY VISIBILITY

Although the initial conceptual view of lines-of-sight in a city is simply that across streets, more intensive examination of all of the types of patterns of occupance of urban land quickly reveals that there are numerous situations where the concept of buildings lines up along a street does not apply. A more open aspect is found especially in newer, planned developments located either in redevelopment areas or in new, planned projects at the edge of the city. Streets and drives serve these areas but the impact of their planned arrangement dominates. Buildings are arranged in accordance with strict plans and are separated from one another in all directions.

Very simply put, there are just three basic patterns of placement of buildings on urban lots. They are (1) aligned attached, (2) aligned detached, and (3) nonaligned detached. The first is found typically in downtown areas where buildings are set wall to wall so that each may gain maximum exposure to the street (the right side of Figure 29 is an example). The second is seen in a detached housing residential area (Figure 30, left side). The third, the nonaligned detached, is becoming more common and appears in outer-city developments (Figure 31), in planned unit development residential areas and in rebuilt central city areas.

The following discusses the lines-of-sight associated with seven different spatial patterns found in representative cities. Three of these are contrasting pairs. They are designed to compare lines-of-sight between sections of cities and between cities of different countries and regions. Another, Figure 31, represents a typical "Outer-City" development.

The first pair (Figure 29) contrasts the sharp differences in line-of-sight distances which exist between a modern downtown redevelopment area and a tightly knit traditional central business district. The former, in San Jose, CA, represents a planned development in which free-standing buildings have been placed on "super blocks" in an area in which the U.S. Housing and Urban Development Department razed an old section of the city. Buildings are steel/concrete-framed structures and are separated by wide streets and landscaped grounds. In this example of nonaligned detached placement, lines-of-sight are in all directions, not just across streets.

The pattern in San Jose, Costa Rica, by contrast, is typical of Spanish colonial cities with its square blocks (one mensana in size, 80 varas, or paces, on each side) and narrow streets (of about 10 m wide). Buildings completely cover the blocks in most cases; non-built-upon spaces are but minor courtyards and places where buildings have been razed. The only significant open spot is the block occupied by the downtown's principal plaza.

Lines-of-sight were drawn between buildings in the California example and across streets (and the plaza) in the Costa Rican example. These distances were then averaged. The mean distance of 66.8 m for the San Jose, CA, example is considerably greater than the 18.8 m average for San Jose, Costa Rica.

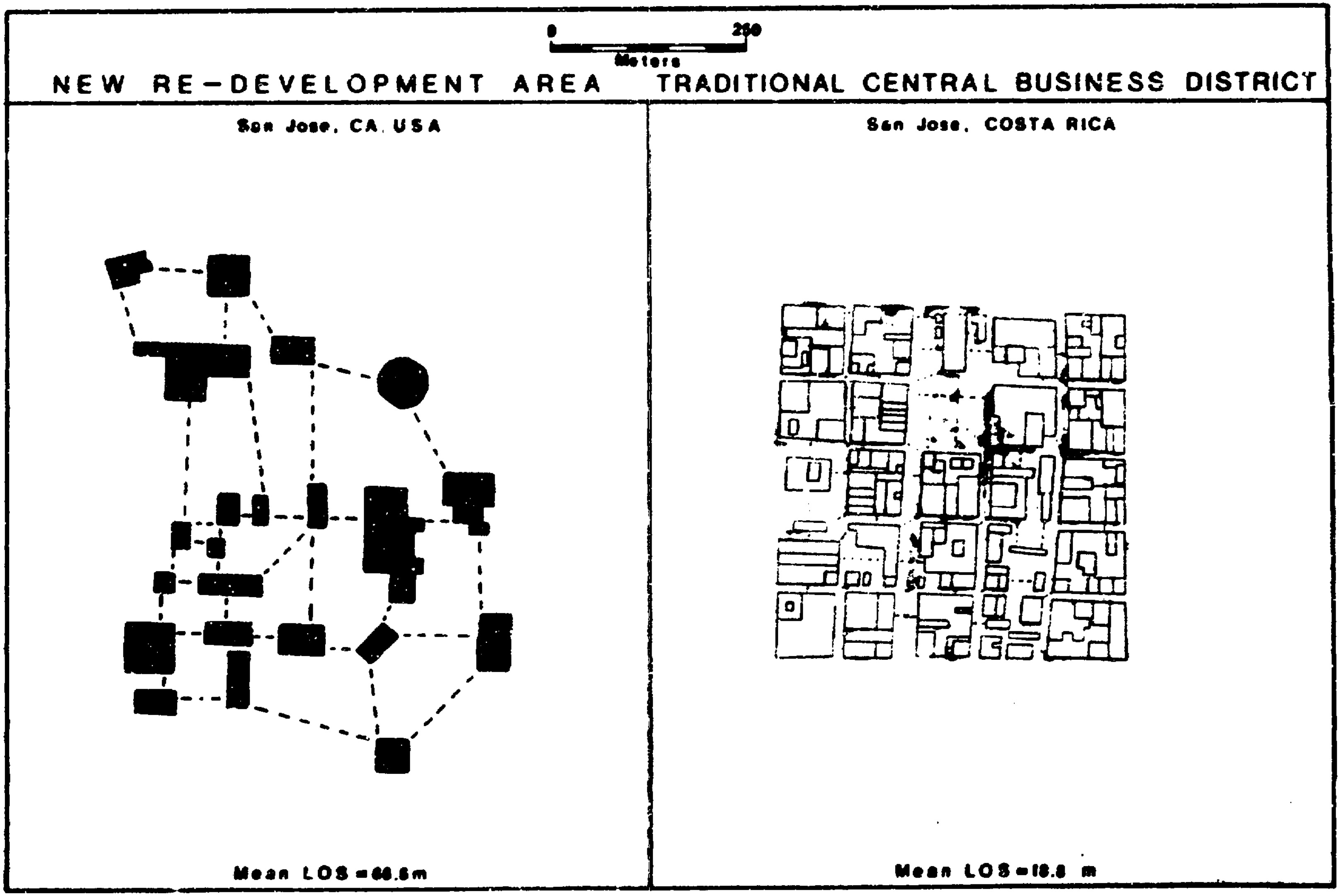


Figure 29. Lines-of-Sight Distances
Business Districts

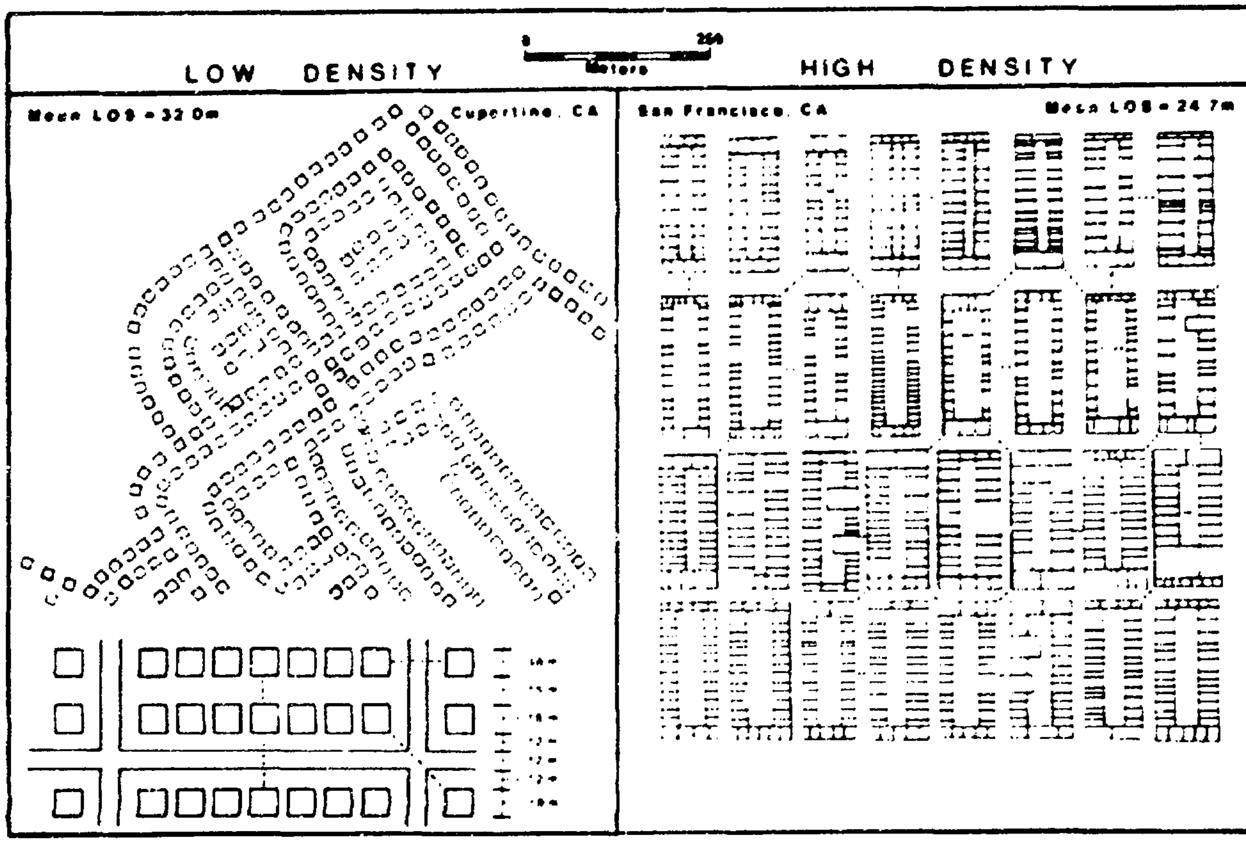


Figure 30. Lines-of-Sight Distances
Residential Areas

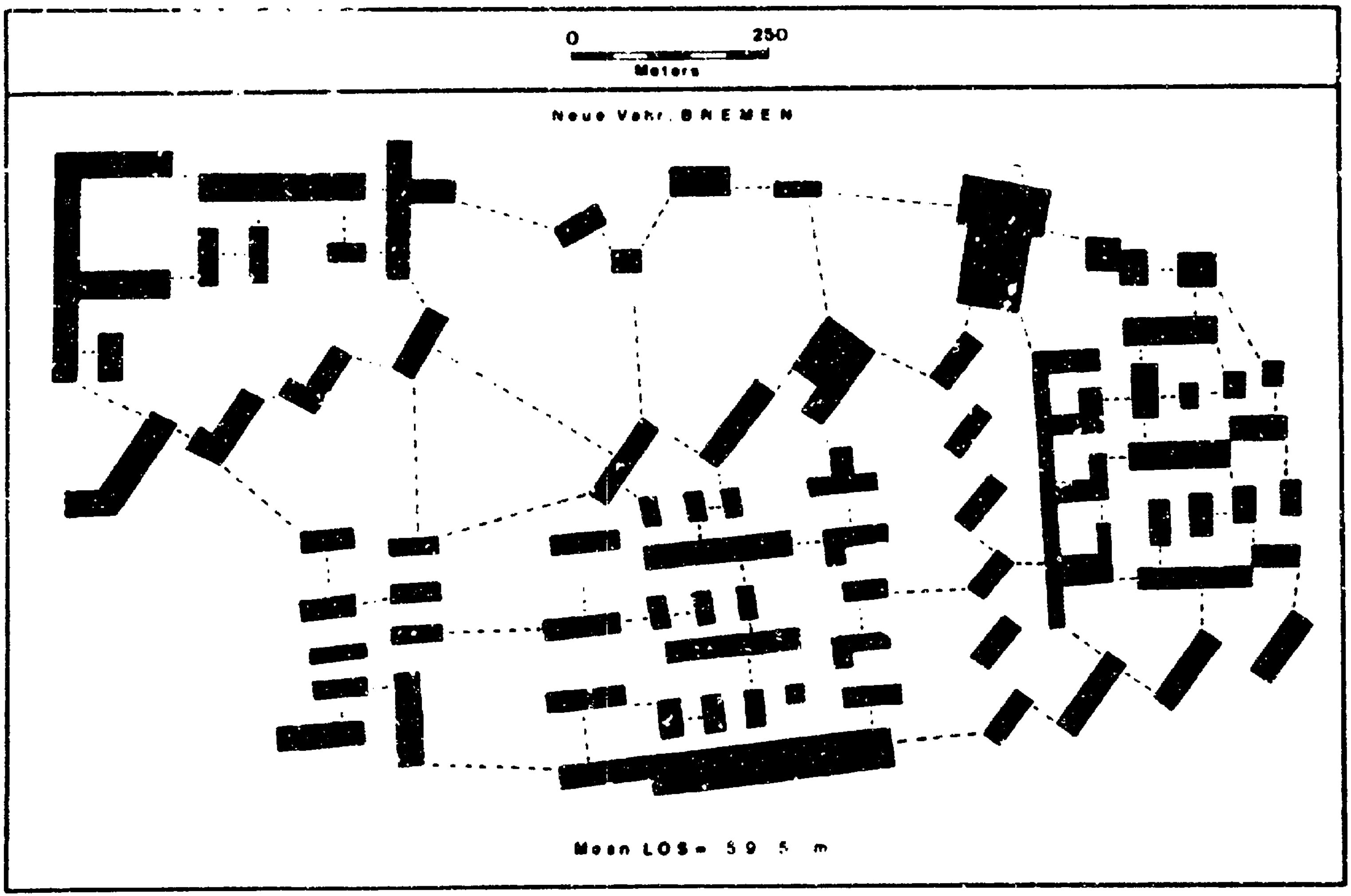


Figure 31. Lines-of-Sight Distances
Outer City

A most important consideration in this comparison is recognizing that the two radically different patterns are frequently found side by side within the same downtown, central city area. Reasons vary. In some instances there has been planned redevelopment of decayed parts of the central business districts; U.S. urban redevelopment areas are good examples. In other instances, such as in cities which suffered heavy structural war damage, newly styled areas with their free-standing buildings stand in marked contrast with older, more tightly knit forms. In yet other cities, growth has been so rapid that there are sizable areas of new forms which have been appended to the older.

Military planning implications are clear. Operations in the open-style (nonaligned detached) type of area, with its long lines-of-sight, permit the use of different tactics and weapons than those which must be employed in the high building density areas. Other aspects of military planning are also potentially involved. Communications, logistics, transportation, and air-support activities all must cope with the basic differences in these two types of urban environments.

The same general theme is pursued in an examination of the varying situations with two levels of building density for wholesale-industrial districts (Figure 32). The higher density of structures in the Berkeley, CA, example typifies what is often found in older, fully developed districts. The high density of (often smaller) buildings traditionally occurs where such districts were placed along rail lines. Such high concentrations permitted economic servicing by rail spurs. Because these districts were located close to other major sections of a city, there was a further desire to have them as concentrated as possible to contain such land uses and to permit the highest possible accessibility by mass surface transportation. Reduced distance to the major market, the central city, was another consideration in their planning.

The Santa Clara, CA, example typifies modern areas. These are composed of fewer, usually larger, buildings and are set farther apart than the older types. They are ordinarily located within planned industrial/business parks. Access to freeway interchanges is favored over that to railroad lines. Because of the need for space for motor trucks, there are wide roadway arterials within. The provision of large parking lots for the automobile-driving commuter workers uses yet greater amounts of space.

The net result is a significant difference in the lengths of lines-of-sight. 41.6 m for the high-density example and 58.9 m for the low-density one. Implications for military planning are similar to the situation encountered for the previous comparison but to a lesser degree. The probable differences in types of buildings found in the two must be considered. In the higher-density area, older forms of construction are the mode. Steel and concrete buildings are common. These have large window areas and generally light cladding, sometimes only sheet, corrugated steel. The low-density area is more likely to consist almost entirely of reinforced concrete tilt-up structures, although more so in the United States than elsewhere. Thus, while lines-of-sight are shorter in the higher-density area, penetrability of walls [illegible] be easier.

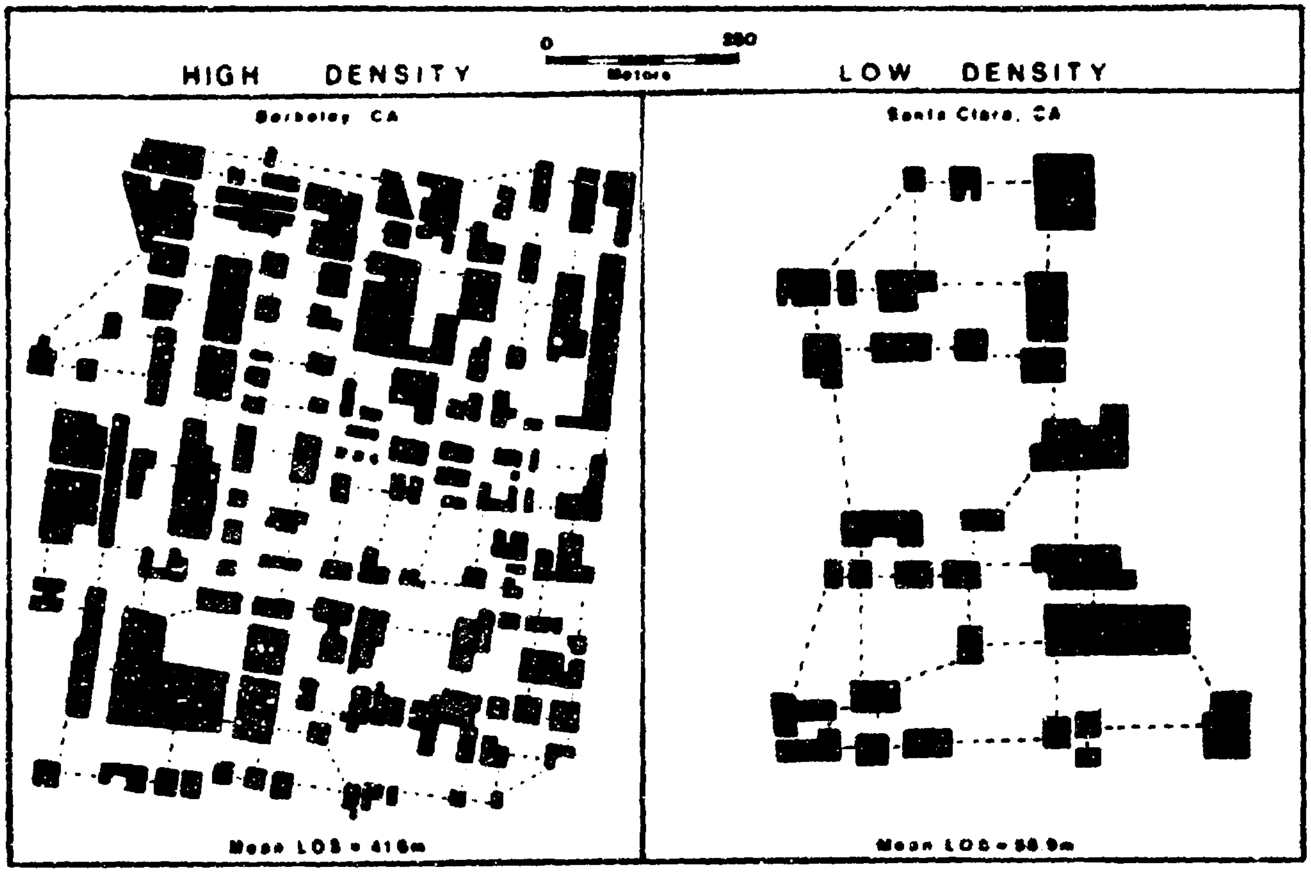


Figure 32. Lines-of-Sight Distances
Wholesale-Industrial Districts

Contrasting residential areas are examined in Figure 30. The low-density example in Cupertino, CA, is typical of single-family detached housing suburban sprawl (aligned, detached). Houses are set back from the curb a distance which is as great as that of the street itself (12 m). Another 15 m of separation occurs between the rear elevations of houses on bordering lots. The structures themselves are 18 m deep. Streets are intentionally curved to be pleasing aesthetically and to slow vehicular traffic flow. Line-of-sight measurement consists of across-street distances, at corners, and across back yards. The product is an average of 32.0 m.

The situation in the high-density example, a neighborhood in San Francisco, CA, (aligned, attached) displays the more traditional mode of rectangular blocks and straight streets. Houses occupy the full width of their lots giving a visual impression of common wall construction even though each building was erected independently.

Open space in the area consists of the streets and the narrow back yards. The average of measurements made across them reaches a figure of only 24.7 m. While this example comes from the United States, the form is common in Europe and lines-of-sight are similar.

The final example is that of Neue Vahr (Figure 31), a planned outer-city development in Bremen, FRG. A mix of apartment buildings of various sizes and types occupies a well-planned, arranged site (nonaligned, detached). Broad avenues, walk ways, landscaped grounds, and athletic fields separate the buildings. Some distances between buildings are extraordinarily wide, enough so to cause the mean line-of-sight distance to reach the figure 59.5 m.

Table 13 summarizes the line-of-sight distances for all of the examples Most significant is the great range found. The existence of large areas within cities with line-of-sight distances ranging from 32.0 to 66.6 m serves to cause the modification of the sometimes held notion that all urban situations consist of solidly packed ranks of buildings with no setbacks facing relatively narrow streets. The spatial patterns of modern cities are much more varied than such an image contends. Accordingly, a variety of situations and urban environments must be considered by military planning.

In a search for the finest level of detail possible for evaluating surface lines-of-sight, precise measurements were made in the old city (Altstadt) of Bremen of both street width and visibility along streets. The street pattern and the widths are typical of many European cities which still reflect characteristics which were established in the Middle Ages and have changed little since with the exception of some street widening and realignment in postwar rebuilding. Availability of large-scale, accurate maps and aerial photography plus field verification assure that the measurements are accurate.

The map (Figure 33) indicates the horizontal along-street, measurements made. They are the longest, clear lines possible either across an open space or before a curve in the street causes a visual obstruction. A total of 92

Table 13. Lines-of-Sight Distances

Primary Types of Urban Functional Zones

Functional Zone Type	Test Site	Lines-of-Sight Avg. Distances (m)
Business-Commercial Areas		
Downtown Urban Redev. Area	San Jose, CA, U.S.A.	66.6
Traditional Central Business Dist.	San Jose, Costa Rica	18.8
Outer City (Residential/Commercial)	Neue Vahr, Bremen, FRG	59.5
Wholesale/Industrial		
Low Density	Santa Clara, CA, U.S.A.	58.9
High Density	Berkeley, CA, U.S.A.	41.6
Residential (Detached Houses)		
Low Density	Cupertino, CA, U.S.A.	32.0
High Density	San Francisco, CA, U.S.A.	24.7

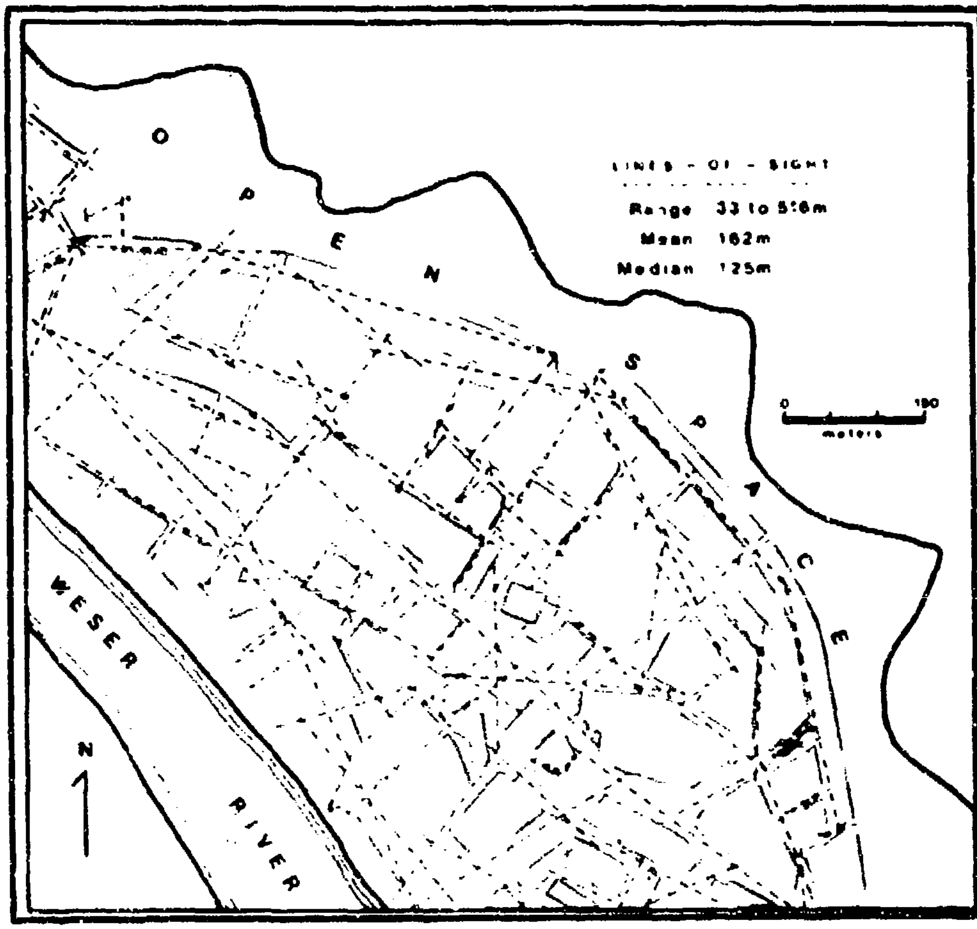


Figure 33. Horizontal Lines-of-Sight Along Streets
Altstadt, Bremen

measurements were made using the linear measurement device on a Numonics electronic planimeter/digitizer. The gross length was 14,936 m, the mean length was 162 m; and the median was 125 m. Measured lines-of-sight ranged from 33 m to 516 m.

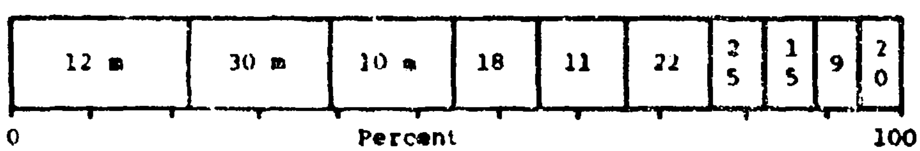
An extremely accurate measurement of across-the-street lines-of-sight (see Table 14) was achieved for the same area (Altstadt) in Bremen by first measuring the width and length of 66 separate streets. The total length of street in each width class could thus be calculated and the collective mean established. By this process, the resulting mean was 17.4 m. The standard deviation of ±7.7 m indicates a small range between the narrowest and the widest streets. Employing the measurement of both length and width in the calculation provides a more comprehensive, reliable figure than results from the simple sampling of widths alone. It should serve better to provide the kind of parameter required by military planning.

Table 14. Across-the-Street Lines-of-Sight

Streets			
No.	Width (m)	Length (m)	Percent of Total
3	9	230	3.1
12	10	1,240	16.6
6	11	580	7.8
19	12	1,830	24.6
4	15	290	3.9
4	18	760	10.[illegible]
2	20	200	2.7
5	22	470	6.3
2	25	320	4.3
9	30	1,530	20.5

Mean Street Width: 17.4 m
Standard Deviation: ±7.7 m

Distribution



The distribution chart in Table 14 shows the rank ordering of street widths. It demonstrates a bimodality in which the narrow 12-m and 10-m streets collectively account for 41.3 percent of all streets, while the broadest lines-of-sight in the measured area (30 m) accounted for 20.6 percent. These latter lengths are accounted for by the lines-of-sight across the squares and market place in the very heart of the city.

In a broader test (Figure 34) horizontal along-the-street measurements were made for an area which is virtually all of the built-up area of Bremen. In this test, the configuration of streets was regionalized. Regions where open, unobstructed lines-of-sight along straight streets did not reach 500 m were placed in one class. (The distance of 500 m was selected as the nominal accurate range for small arms fire.) The situation causing lines-of-sight not to exceed 500 m occurs where there are short streets connecting paralleling arterials and where there are T-shaped intersections. The average line-of-sight for all streets in this class was 230 m (Table 15) in a sample of 154 streets. They are concentrated largely in a zone just beyond the old, original center of the city, an area built up mostly during the nineteenth century. The areas with lines-of-sight greater than 500 m are associated mostly with post World War II surburban developments and the industrial and dock areas.

Table 15. Surface Horizontal Lines-of-Sight

Bremen, West Germany

Street Type	Average LOS (m)	Sample No. Streets	Area (ha)	Street Density per km^2
Straight Streets Less than 500 m	230	154	399	40
Curved Streets Less than 500 m	159	136	68	200

The curved streets with lines-of-sight less than 500 m had shorter averages (159 m). Their location on the map (Figure 34), located as they are both in the older central city and the farther reaches of suburbia, expresses two spatial phenomena. In the old city, the curved streets are vestigial from the Middle Ages; in suburbia they are planned designs for model residential communities.

A comparison of densities of these two classes yields further interest (Table 15). As might be anticipated, the density of straight streets is far less--at 40 streets per km^2--than the curved streets where there are 200 per km^2.

It is suggested that measurements of this type provide military planners with a useful means of evaluating the difficulty of operations within the city. The use of such index figures as street densities has possible utility in

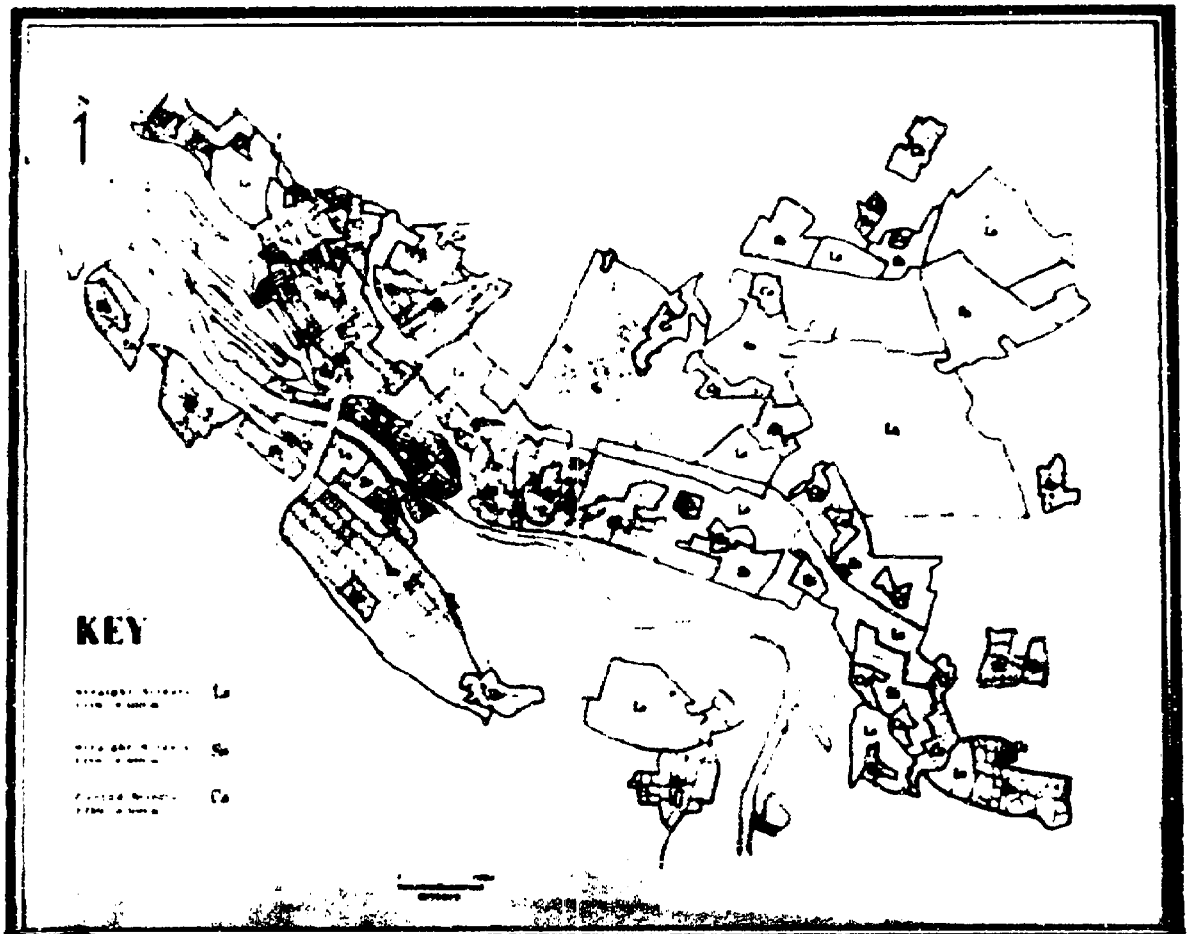


Figure 34. Line-of-Sight Regions
Bremen

several ways. The mapped features provide necessary spatial information, especially in evaluating ingress and egress. Potential areas of difficulty of defense and offense can be delimited. Comparisons with numerous cities would serve to establish the sort of replicative generalizations with which to develop doctrine and training.

5.3 CHARACTERISTICS AND PROBLEMS OF LINE-OF-SIGHT IN LIMITED VISIBILITY URBAN SITUATIONS

Concern has often been expressed over the potential restrictions which the highly concentrated sectors of the urban environment could place upon the employment of shoulder-carried assault weapons. One potential difficulty is seen to result from firing such a weapon across streets which are narrower than the recommended safe arming distance of the warhead. Another difficulty is perceived in attempting to fire across and down a street to a point where maximum angles of obliquity would be exceeded. That the urban environment does pose these kinds of restrictions is confirmed by measurements made in this and the previous study completed for NSWC (Urban Building Characteristics).

The potential problems to be confronted are shown graphically in Figures 35 and 36. In these examples, two assumptions are taken: (1) that the minimum arming distance is 15 m, and (2) that the maximum allowable angle of obliquity is 45 degrees. These figures are, of course, taken only as working numbers. The plotting of other higher and lower numbers might prove useful; the values used here are held to be representative of the problem.

Using these parameters (Figure 35), the full width of a target (between the limits of obliquity) may be acquired when street widths exceed 15 m. For a street 15 m wide, the width of the target (between the 45-degree angles) is 30 m. This effective target zone widens with increasing distance until (on the diagram) it reaches 40 m at a distance of 20 m from the firing position.

For street widths below 15 m, the size of the target which may be acquired within the given parameters rapidly becomes smaller. The shaded area in Figure 35 represents the area where adherence to minimum arming distance and obliquity will not allow usage of the weapon. Examining street widths lying between 11 and 14 m in detail (Figure 36), we observe that the potentially acquired target width diminishes quickly from 8.6 m for a 14-m wide street to 5.5 m for a 13-m street, to 3.0 m for a 12-m street and then to 80 cm for an 11-m street. For streets which are narrower than 11 m, there is no possibility at all of acquiring a target. All of these figures presume a firing position at the front face of one building looking across the street at a target building. Obviously, target acquisition width could be increased by firing from within a room. Consideration of such an operation opens the whole question of gaining entrance into buildings, facing back-blast and noise problems, acquiring firing positions on upper floors, and breaching partitions laterally within buildings and exterior walls of adjoining buildings.

The restrictions posed by narrow street situations have potential significance to tactics and doctrine planning and development. If given the validity

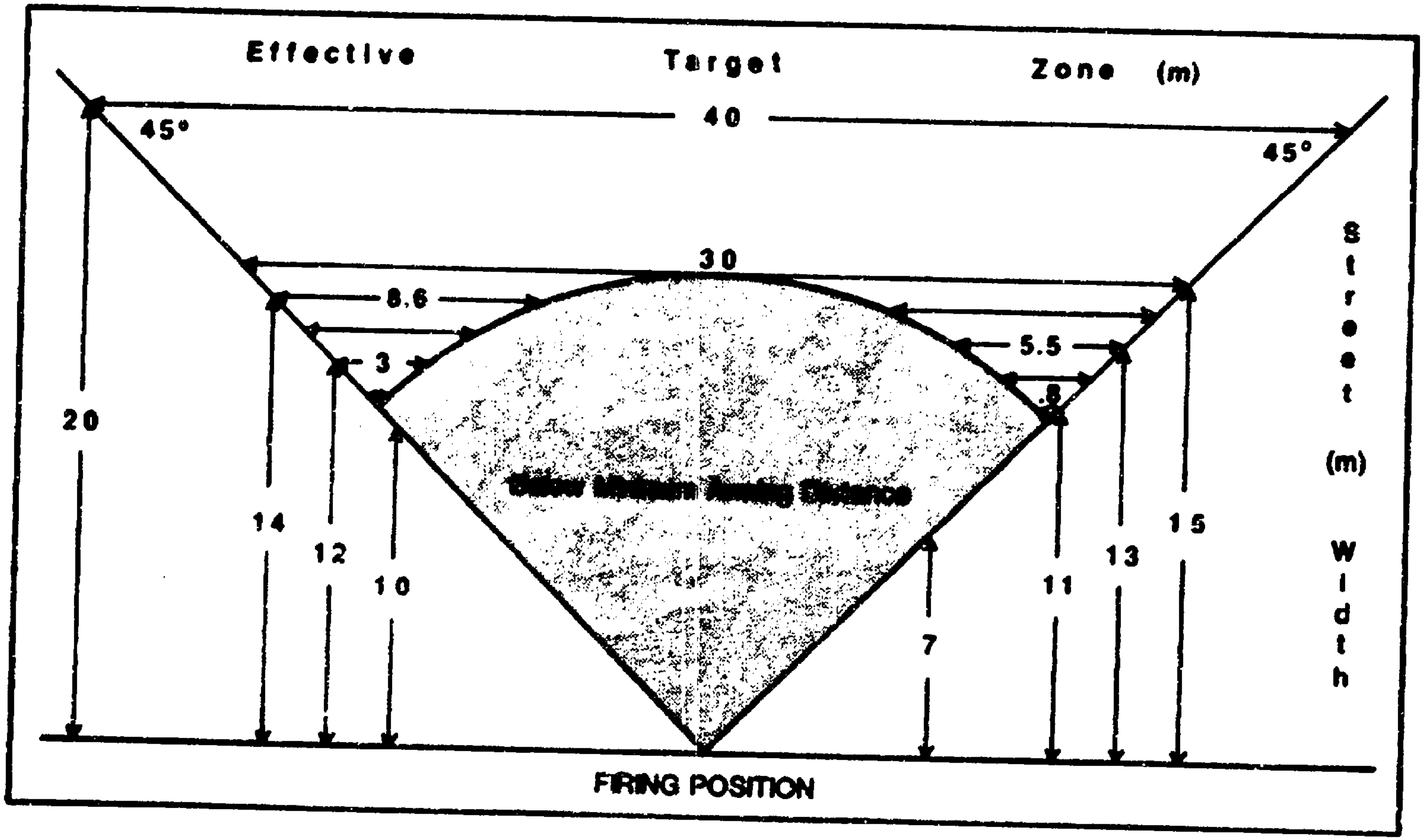


Figure 35. Street Width/Target Acquisition; Application of Minimum Arming Distance and Acceptable Angles of Obliquity

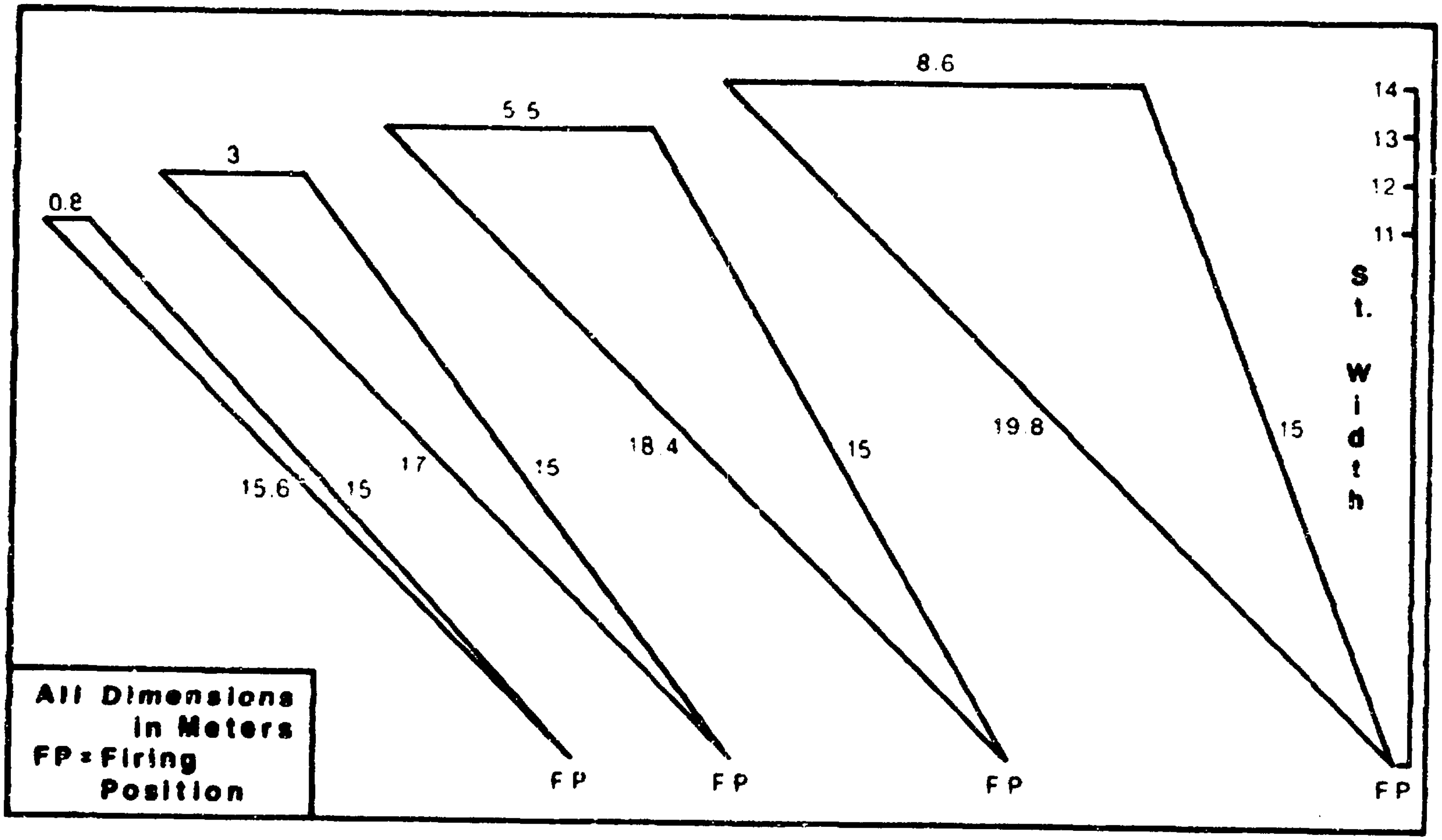


Figure 36. Target Acquisition Cones
Street Widths of 11-14 m

of the parameters assumed, an assault weapon cannot be used efficiently in such situations, the suggestion is clear that alternatives should be sought. Of course, the proportion of all cities in the world which present such restrictions is relatively small. Reference again to Table 11 reveals that only 17.2 percent of the area of the studied cities lies within the 7- to 15-m street width range. These do vary regionally, however, and cities within certain regions (Figure 28) such as Asia and Latin America, have sizable portions of cities with narrow streets. Such sections also are found in small, but important, cores of cities such as was demonstrated in the case of the Altstadt of Bremen (Table 14).

A task is perceived here for military planners to evaluate the internal street geography of cities of interest and to determine just how important to the total mission operations would be in the narrowest confines of the city. The unanswered question remains: are these narrow street areas different in kind or only different in degree? And, do they require special considerations for all types of military planning, weapons development, tactics, logistics, etc.?

Special attention needs to be given to street intersections for it is here that the visibility situation is significantly different than that encountered in the "across-the-street" conditions. The ability to see down, across, and along two streets (see Figure 37) gives these corner positions a big advantage as firing positions. The example contrasts the "normal" corner, where structures are built right up to the corner of the lot, with a building which has an angled ("double") corner. For the latter, not an uncommon situation, the visibility cone is considerably greater than that of the normal corner. The biggest single advantage of the corner situation for the defender is the virtual elimination of the minimum arming distance problem for all but the narrowest of streets. Angles of obliquity still impose restrictions, however.

Bremen was examined to determine the incidence of types of intersection (Figure 38). Cross-shaped intersections formed the largest proportion of the total. Intersections where a street dead-ended into an arterial ("T" intersections) are similar situations. Angled "T" intersections and irregular intersections present a more complex line-of-sight problem.

5.4 STREET AREA TO BUILDING FLOOR AREA RATIOS

The conceptual view of a city does not consist of buildings and streets independently but rather of the collective impression of the two in combination. The concept is traditionally developed from the viewpoint of the observer who is located, primarily, on the street looking at the profile of the buildings bordering it. The view is three dimensional, of course, but within this the horizontal plane of the street and the vertical of the buildings dominate.

Given that the streets and the buildings are the two primary elements of the urban environment, a means is presented here to quantify the relationship between them with a view toward developing ratios which could serve to indicate degrees of intensity. In crowded downtown situations, in reaction to the

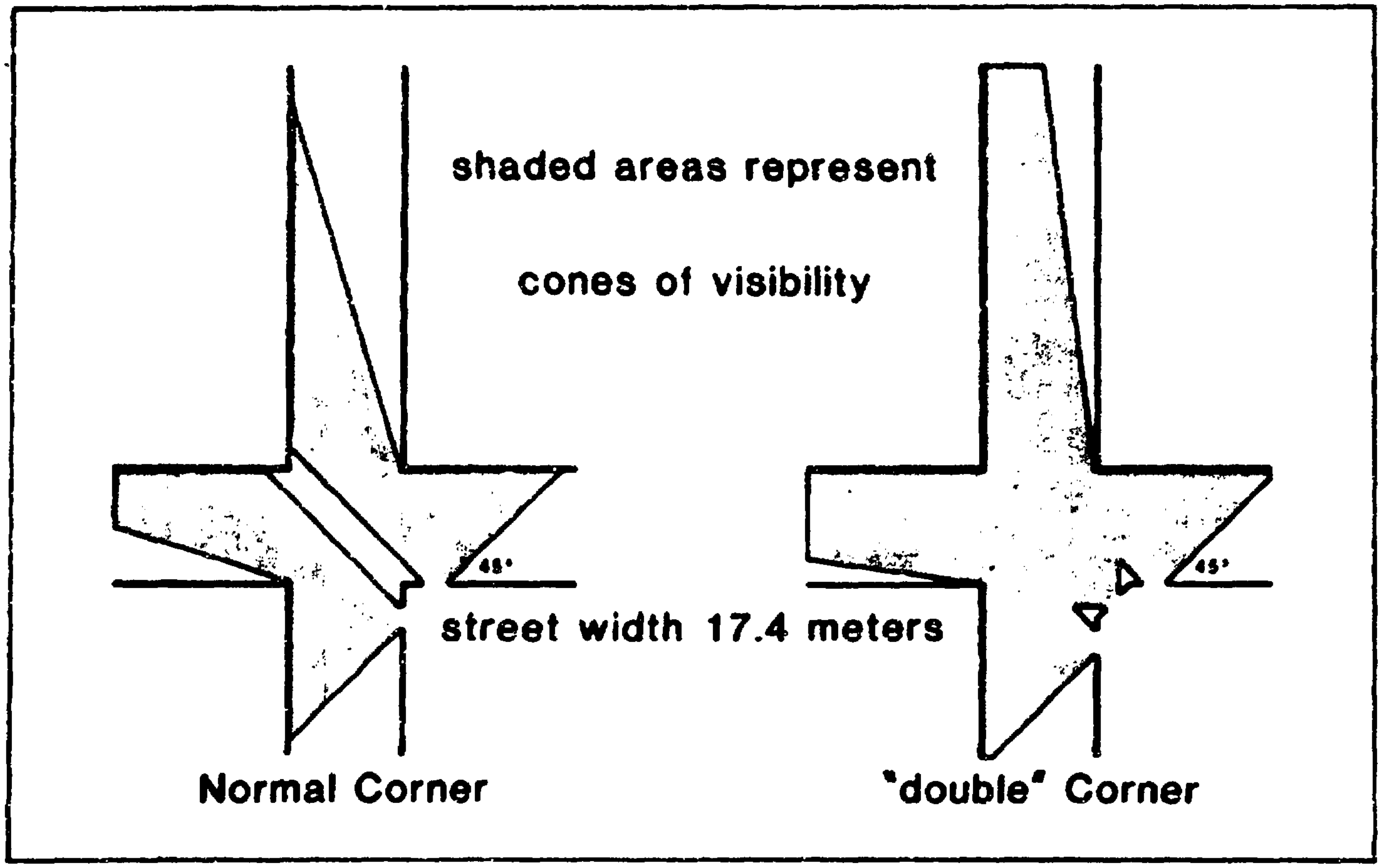


Figure 37. Visibility Situation of Upper-Floor Corner-Firing Positions for Masonry Buildings

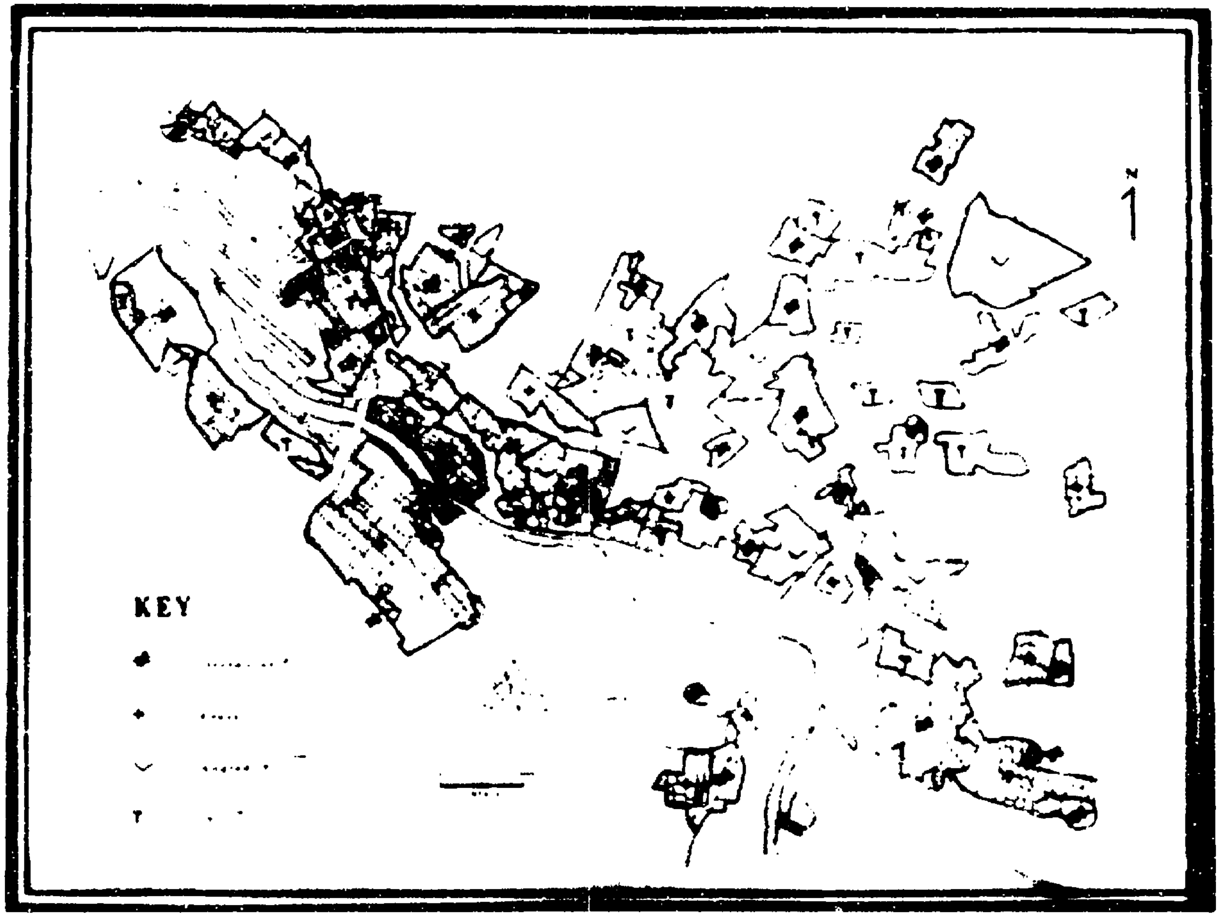


Figure 38. Types of Street Intersections
Bremen

desire to make maximal use of high-value land, buildings cover virtually all space except that required for the streets necessary for articulation. The ground-floor area of blocks is obviously greater than that of the streets which serve them. When a multiplication of surface space is considered, as results from construction of multistory buildings, the total floor space vastly exceeds that of the non-built-upon ground space represented by the streets (and some open spaces). Measurements of street and floor areas of adjacent buildings in the accompanying diagrams provide a series of ratios. Plotting of these on maps of real cities (Bremen and Casablanca) provides spatial patterns of these phenomena.

A potential military value is anticipated. From the attackers point of view, the streets represent the obvious lines of access and the buildings represent the objectives. When, as is common, the buildings are multistory, it is the total floor space which can become the objective. Thus, from a purely hypothetical point of view, when the streets are narrow and the buildings tall, the ratio of floor space (potentially occupied by the enemy) can far exceed the area of the access routes (the streets). This means further that the defenders can be dispersed over a considerable amount of space while the attacker is concentrated on the street.

5.4.1 Method

The end goal of the method was to arrive at a ratio of street area to floor area. In particular, this means establishing that for a square meter of street space there were x square meters of floor space in the buildings facing that street.

Arriving at these figures required manipulating previously gained data on the average street width and the average number of floors for buildings. To these were added measurements of lengths of streets for each building and street region. Using these data (see Table 16), the ratio of street area to building floor area was determined by relating total street area (width time length) to total building floor area (derived by multiplying the average number of floors by the area of ground covered by buildings.)

5.4.2 Findings

Table 16 presents the data in order of descending ratio density. The highest ratios occur where concrete-framed buildings average seven stories high and face streets which average 11 m wide. The lowest ratios are found where brick buildings average four floors and have frontage on streets which average 20 m in width.

The ratios acquire a greater significance when plotted in a real-world situation (the map of Bremen, Figure 39). Highest ratios occur, expectedly, in the center of the city (the old section with its high-rise buildings and narrow streets). Two large areas of the second highest ratios are found,

Table 16. Building Floor Area Relative to Street Area

Street/Building Floor Space Ratios

Bremen

Structure Type	Buildings: Height (stories)	Buildings: Average No. of Stories	Buildings: Total Area (ha)	Buildings: Total Floor Space (ha)	Streets: Width (m)	Streets: Average Width (m)	Streets: Total Area (ha)	Streets: Total Length (m)	Distance from City Center (m)	Ratios of St. Area to Building Floor Area
Concrete Framed	4-10	7	13	88	7-15	11	3	3,132	310	25.8
Brick	2-5	4	162	648	7-15	11	40	36,407	752	16.2
Concrete Framed	4-10	7	33	231	15-25	20	22	11,122	603	10.5
Concrete Framed	7-17	12	12	144	15-40	28	17	6,015	613	8.4
Concrete Framed	2-8	5	59	295	15-50	33	35	10,513	1,288	8.4
Brick	2-5	4	58	232	15-25	20	31	15,651	862	7.4

$^{a}\frac{\text{Floor Space}}{\text{Street Area}}$ = it establishes a ratio between street area and floor space, e.g., 1 m^2 of street = 25.8 m^2 of building floor space.

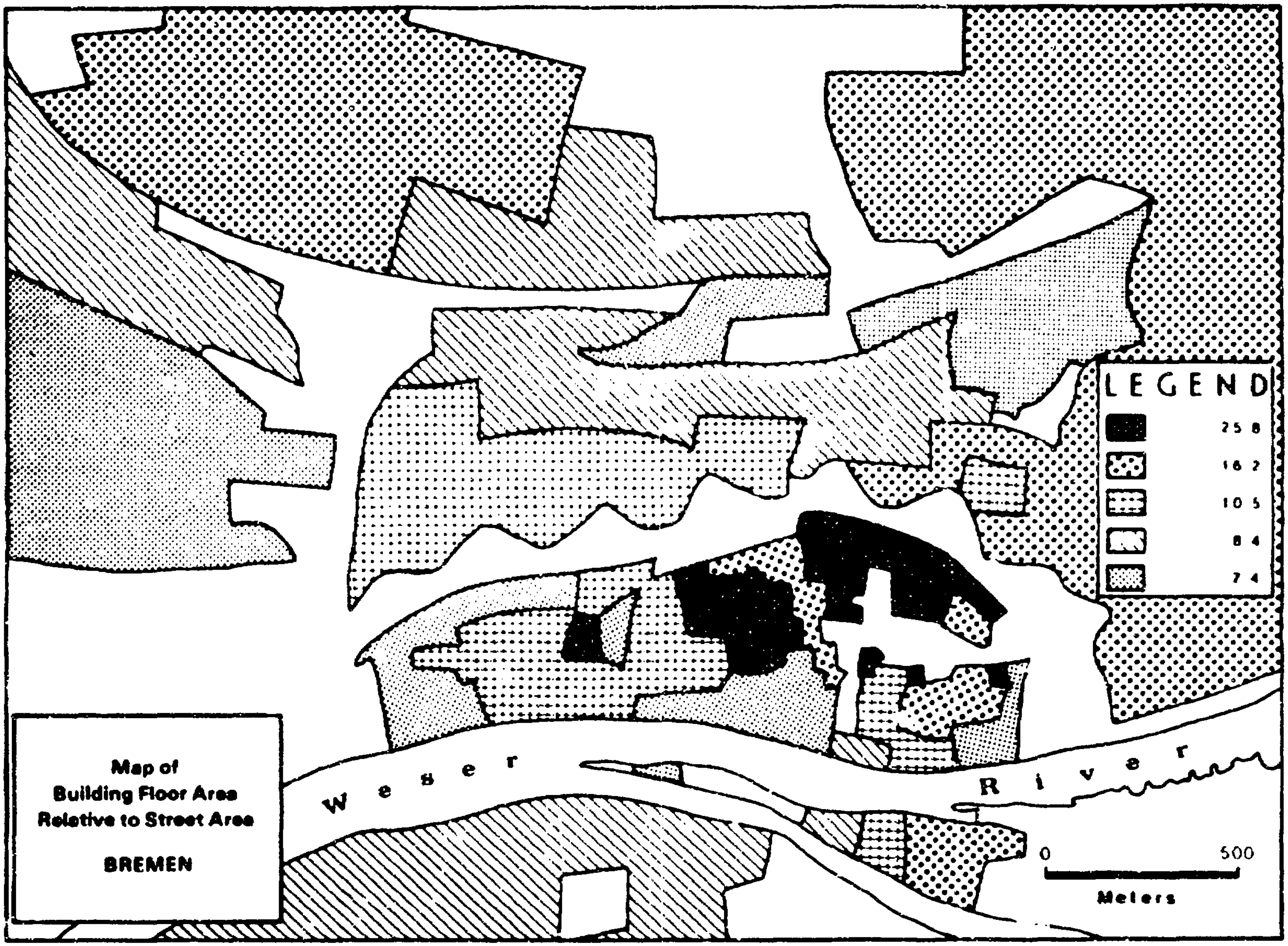


Figure 39. Building Floor Area Relative to Street Area
Bremen

however, farther out (note that not all of the city is mapped in this example--lower ratio suburbs lie beyond). These second highest ratio areas result from large areas of brick buildings averaging four stories high facing fairly narrow streets. The lowest four ratios (all nearly the same values) are found both in and near the center and out at the edges.

Several military inferences are possible to take upon examination of the areal pattern presented here. For one, while the center has potentially the most difficult area, it also has some of the lowest ratio areas. This is probably common to many cities considering that the centers often have representatives of both the old and the new. The implication is that military operations in the center of a city could be difficult in one place, easy in another.

The presence of such a high ratio (16.2) for much of the area on the east and north of the mapped segment is also not uncommon, representing as it does the large areas of middle-height brick structures (mostly apartment houses) which lie out beyond the city core. These could pose a serious threat to ingress to the center.

The remaining lower ratio areas are where there are such low-rise buildings as factories, warehouses, and smaller residences all facing either wider streets or non-built-upon spaces for storage, railroad tracks, etc.

This analysis of the city is but a step toward developing a more complex index which could indicate potential difficulty of conducting military operations in cities. One addition to the formula to create the index would be the impact of type of building relative to its height. For example, each floor of buildings with load-bearing walls (brick) could well be a formidable obstacle. Light-cladded framed buildings, by contrast, offer little protection to defenders in their upper stories. Accordingly, these buildings (and all others) could be given an appropriately weighted factor. Height alone may not be as important as the ratios suggest. If doctrine, both defensive and offensive, called for not using or being concerned about upper floors, then a weighting factor could be introduced. The amount of weighting could come only as a result of a full analysis of all factors. The end product, an "index of the degree of complexity," could be applied to a number of test urban situations. The results could prove to have high value.

5.4.3 The Casablanca Example

The same method was employed in an analysis of Casablanca. Again street length measurements were added to data acquired earlier and ratios were computed.

Some of the results were similar to those found in Bremen; some varied. The high ratio of 39.3 (Table 17) in Casablanca reflects the presence of a larger area of tall buildings than is found in Bremen. Because of the rules followed in determining the ratio, the tall (average 13 story) buildings, although located on streets averaging 20 m have enough area (both ground and

Table 17. Building Floor Area Relative to Street Area

Street/Building Floor Space Ratios

CASABLANCA

Structure Type	Buildings: Height (stories)	Buildings: Average No. of Stories	Buildings: Total Area (ha)	Buildings: Total Floor Space (ha)	Streets: Width (m)	Streets: Average Width (m)	Streets: Total Area (ha)	Streets: Total Length (m)	Distance from City Center (m)	Ratios of St. Area to Building Floor Area
Concrete Framed	5-20	13	1[illegible]1	2,266	15-25	20	58	28,870	1,184	39.3
Concrete Wall/ Slab	5-20	7	186	1,302	25-50	45	60	12,882	3,580	22.5
Brick	2-7	5	1,219	6,095	15-25	20	441	220,425	3,000	13.8
Brick	1-3	2	40	80	2-15	11	8	7,[illegible]95	853	10.2
Brick	1-2	1.5	1,109	1,664	7-15	11	231	210,449	3,200	7.2
Concrete Framed	1-5	3	708	2,124	15-25	40	324	81,172	3,616	6.5
Brick	1	1	276	276	15-25	20	164	81,967	2,266	1.7

$\frac{\text{Floor Space}}{\text{Street Area}}$ = it establishes a ratio between street area and floor space, e.g., 1 m^2 of street = 39.3 m^2 of building floor space.

floor space) to yield a high ratio. As befits theory, the region of these high ratios is located in the heart of the city (Figure 40). Areas of second highest ratio (22.5) are associated with high-rise apartment buildings located in several locations outside the center. As with Bremen, there are large areas of brick buildings with an average height of five floors and situated on average 20-m-wide streets. These form nearly 44 percent (in total floor area) of all types. Low ratio areas are composed mostly of low-rise warehouse and factory areas and single-story residential structures.

For Casablanca, the same figures are manipulated into a theoretical model format (Figure 41). In the model, band width is proportional to the amount of floor space of each type. Mean distance outward from the center of the city is also employed. The model provides a better sense of order than the map. It suggests that the most difficult (highest ratio) areas occur in the center but that there exists a fairly low ratio area immediately around this high ratio core. Other high ratio areas occur in rings yet farther out from the center. It may be anticipated that the construction of such models for a wide number of cities could lead to the development of generalizations about the structure of cities which could have possible utility to military planners. It is quite probable that there would be relatively little variation for modeled cities within a single cultural region, such as western Europe. The constructing of models of numerous West German cities could prove fruitful.

5.5 OPEN SPACE WITHIN THE CITY

Emphasis on line-of-sight visibility within the city has been placed on the streets, both across them and along them. Another important component of intra-city visibility is the open spaces. Most of these occur by design and are ordinarily landscaped parks or areas set aside for ceremonial purposes or to provide open vistas across which to view edifices which are designed to be symbols of power and authority. There are classic examples of large open spaces of parkland such as Central Park in New York. Ceremonial areas such as Moscow's Red Square and Mexico City's Zocolo are common. Landscaped backdrops such as the Mall in Washington, DC, or near the Eifel Tower in Paris also occur.

There is potential military significance of these open spaces in that they are areal, angular features rather than linear, as with city streets. Accordingly, several characteristics accrue. Being non-built-upon (with the exception of monuments and the like), they provide broad open fields-of-fire to and from the buildings surrounding them. As large as they are (8.5 ha in the analysis reported on in Table 18), they provide space for the deployment of such tools as tanks and artillery which may not be able to operate on city streets. They also obviously provide space for troop assembly and material storage. Most are also capable of providing areas for helicopter landings and takeoffs. Because of their nature, they are normally devoid of utility lines for aesthetic reasons although trees and monuments are often present.

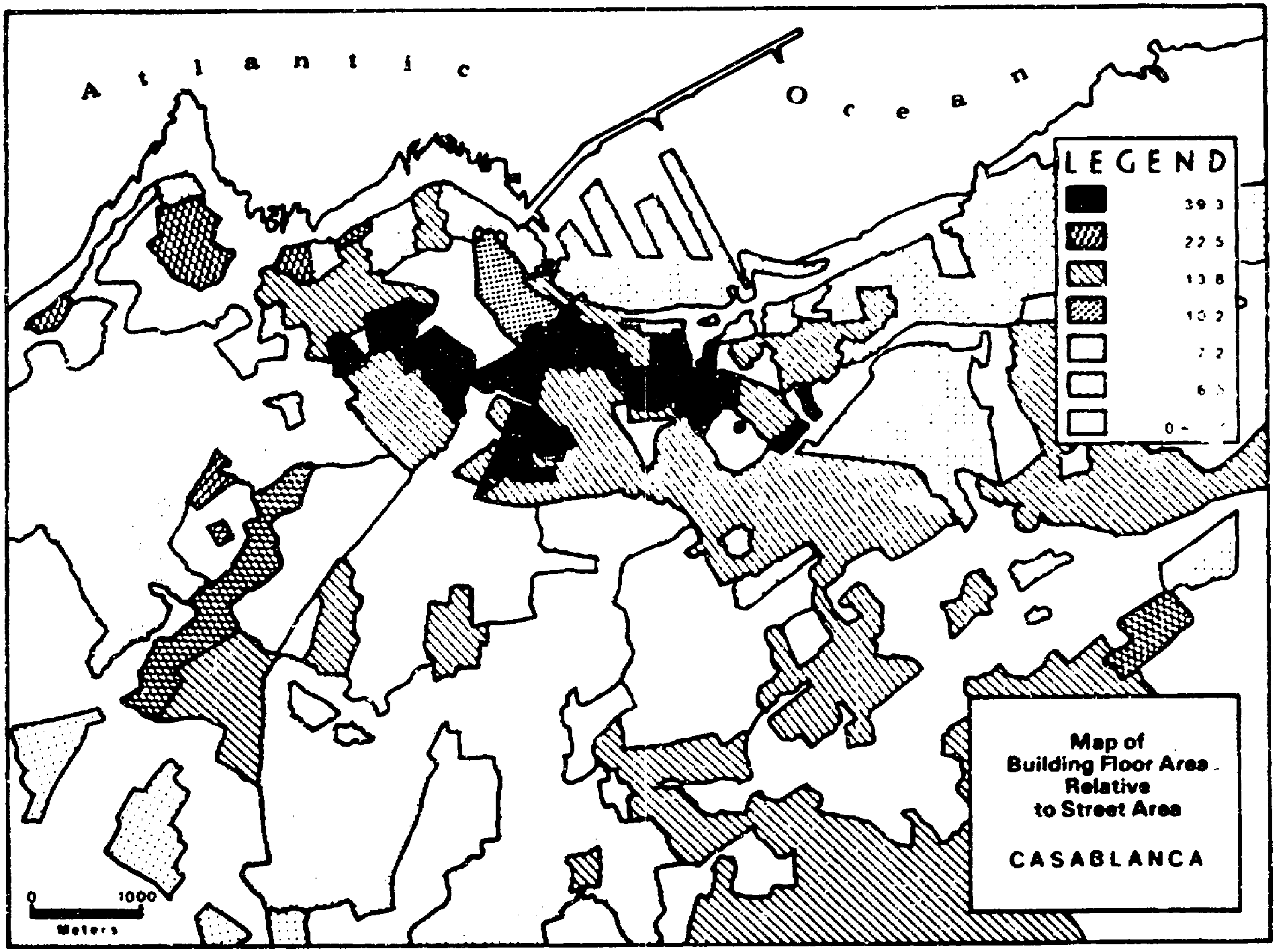


Figure 40. Building Floor Area Relative to Street Area
Casablanca

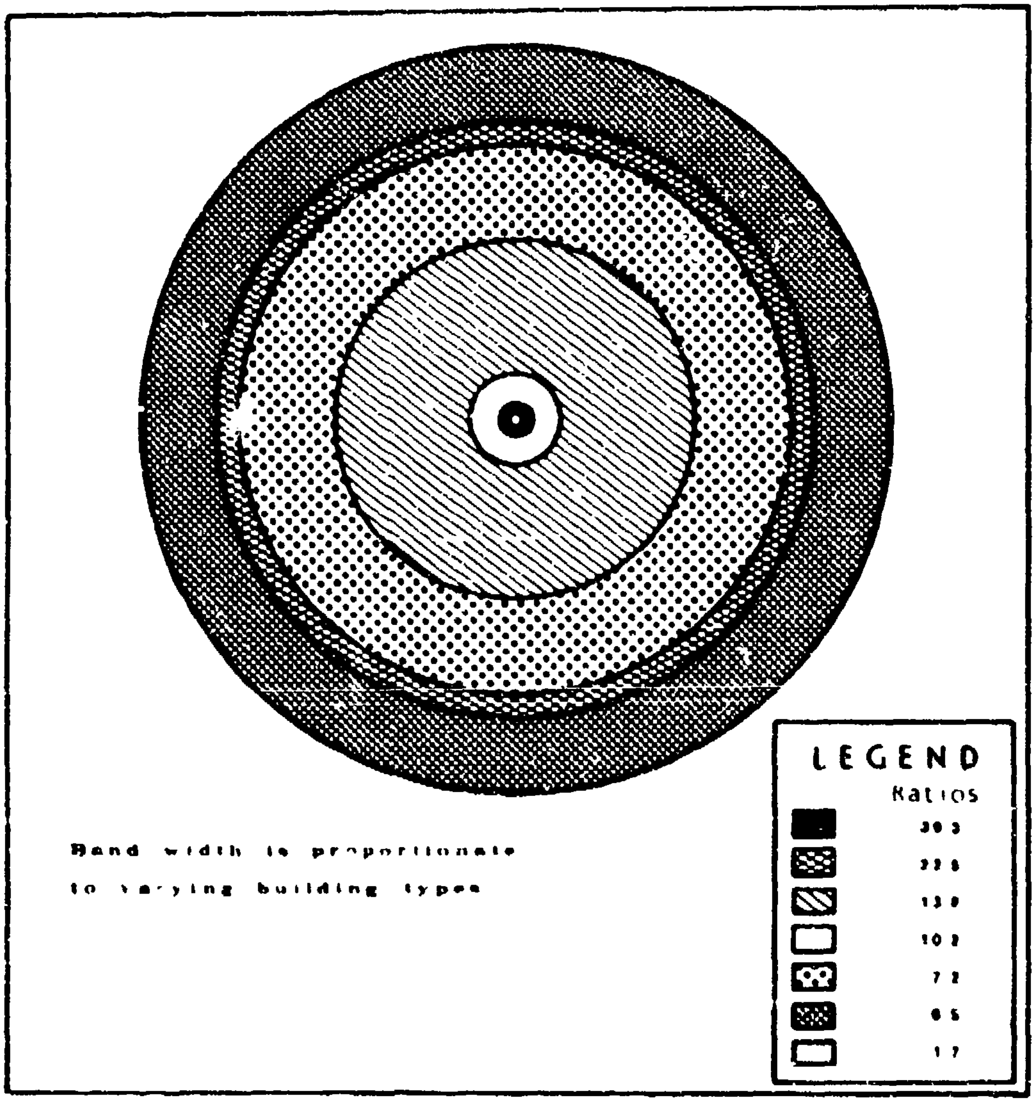


Figure 41. Model of Building Floor Area Relative to Street Area Casablanca

Table 18. Analysis of Close-In Open Spaces
(Lying within a 2-km Radius from City Center)

Number, Area, Network, Density

Region/City	No. of Open Spaces	Total Area (ha)	Avg. Size (ha)	Percent Op. Sp. Total	Avg. Dist* Apart (m)	Avg. Dist. Across (m)
Stavanger	23	103.5	4.5	8.2	212.1	225.3
Bremen	11	220.9	20.1	17.6	397.6	464.8
Leningrad	22	150.4	6.8	12.0	343.6	253.7
Budapest	14	74.4	5.3	5.9	444.7	260.5
EUROPE	*18*	*137.3*	*7.9*	*9.2*	*349.5*	*301.1*
Istanbul	15	88.8	5.9	7.1	456.7	262.6
Casablanca	16	77.8	4.9	6.2	536.0	178.3
Jerusalem	14	197.5	14.1	15.7	399.7	378.7
MID-EAST/N.AF.	*15*	*121.4*	*8.1*	*10.4*	*464.1*	*273.2*
Madras	4	127.8	31.9	10.2	348.8	553.5
Bangkok	6	62.9	10.5	5.0	512.0	347.6
Singapore	11	69.4	6.3	5.5	503.7	216.4
Canton	8	58.5	7.3	4.7	735.6	270.3
Seoul	12	61.5	5.1	4.9	376.0	217.9
ASIA	*8*	*76.0*	*9.3*	*6.1*	*495.6*	*321.1*
San Francisco	10	31.2	3.1	2.5	661.5	189.3
Charleston	5	15.1	3.1	1.2	441.0	178.4
U.S.	*6*	*23.2*	*3.1*	*1.8*	*551.3*	*183.9*
Guatemala City	6	20.1	3.4	1.6	960.6	207.3
Cape Town**	31	99.1	3.2	7.9	200.4	187.8
Mean	13	91.2	8.5	7.7	470.8	274.5
Standard Deviation	7.3	58.5	7.7	4.5	190.7	108.9

*Nearest neighbor
**Cape Town: non-built-upon filled land excluded
Italics = means

Data presented in Table 18 were derived from maps of open space in the original work Urban Building Characteristics. Because city size varied (both in population and area) and because the amount of area varied (the amount of territory covered in each city was a product of available aerial photography), the data were standardized here by measuring the open spaces only for an area lying with a 2-km radius from the center of each city.

Several measurements were made. First, the area of each open space was measured. They were counted and average areas were computed. The proportion of total open space within the 2-km circle was also calculated. Their average distance across was measured as was the average distance separating all open spaces. Samples of phenomena measured appear in the maps of sample cities from each region (Figure 42).

The most remarkable finding (from Table 18) is that the open-space characteristics of the studied cities are so similar. The similarities are: (1) the number of open spaces and the average size show little variation; (2) the average size of open spaces for cities in Europe, the Middle East/North Africa, and Asia is very nearly the same with areas of 7.9, 8.1, and 9.3 ha, respectively; (3) their average distance apart is also quite even varying only from approximately 350 to 496 m; and (4) distance across also varies little ranging from about 273 to 321 m. The two U.S. cities have both fewer and smaller open spaces than their foreign counterparts. This may be somewhat aberrant due to the physical settings of both San Francisco and Charleston. The former is crowded on to the end of a hilly peninsula where space is at a premium and the latter has an analogous position along the narrow flood plain of the Kanawha River.

The consistency and universality demonstrated in the table has interesting military implications. It implies that open spaces are a dependable feature and may be so considered in tactics planning. The network (based on average distance apart) is also a fact of potentially high value.

The few deviations from the norm can be readily explained. The high average size of units in Bremen stems largely from the presence of the large park lying within 2 km of the city center. Other cities have extraordinarily large ceremonial areas, for one reason or another. Jerusalem has its religious areas, Madras has vestiges of grand city planning from British colonial days, and Bangkok has traditional ceremonial open-space features commonly found in a capital city.

5.6 NATURE OF THE URBAN PERIPHERY

Much of the discussion on potential military operations in built-up areas has concerned itself with the intensively developed center of the city. Studies have tended to emphasize the multistory buildings and the relatively narrow streets on which they are found in downtown areas. Even the conceptual image of fighting in cities, as gained from World War II experience and from watching film footage of fighting in such places as Stalingrad and Berlin, has

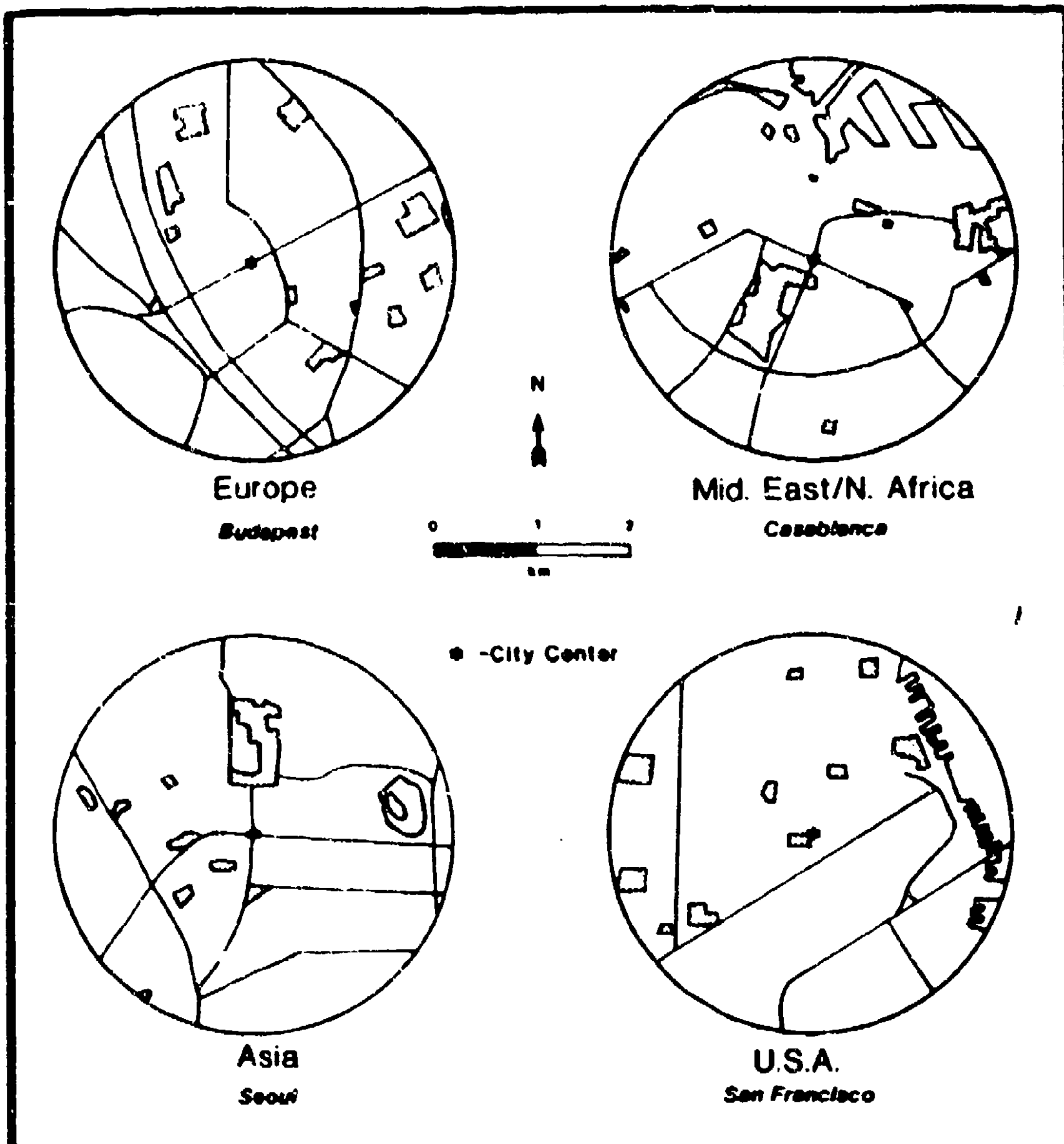


Figure 42. Open-Space Patterns
Sample Cities

generally been one of the urban environment as being composed of tall buildings (usually of masonry construction) with no setback from the street. Much of the tactics planning and the development of doctrine has also posited the urban environment in this way.

Increasingly, a need is being expressed to consider the whole city, that is the entire metropolitan area comprising not just the concentrated center but all of its other components as well. The metropolitan area (defined as the entire contiguously built-up area) is composed of city center, industrial districts, open spaces, engulfed, once-independent urban centers, large areas of housing and their commercial service clusters, and "outer cities" (those planned concentrations of residences, offices, factories, etc., found usually near the periphery of major cities). Several compelling reasons have been brought forth by military planners which suggest that there is a strong need to gain a better understanding of all of the component parts of metropolitan areas.

There is first the suspicion that adherence can no longer be given to the traditional doctrine that fighting in cities should be avoided. This uncertainty stems from the simple fact that cities have so much total area that they block projected routeways across the countryside. This is indeed inherently true when it is considered that not only have cities expanded areally but that they are occupying ever larger proportions of level, easily crossed terrain. Add to this the further concomitant characteristics that cities, by nature, are often located at some strategic junction point such as a road junction or river crossing. In such a position, these expanded metropolitan areas sit astride the natural routeways, blocking advance or retreat.

As a corollary to expanded areal size, there is the fact that even if city centers can be avoided there may still be a necessity to conduct some military operations at the edge of a city in the very process of trying to get around it. At the very least, certain outliers of urban development may sit astride a projected route. The physical nature of these outlying urban areas is quite varied ranging from agricultural villages to industrial complexes. A knowledge of them is essential to military planning.

Yet another concern for the periphery of cities is the announced doctrine of the Soviets (Hemesley, 1977) that, in the event of conflict in northern Europe, they would attempt to take, hold, and fortify the edges of cities to prevent NATO forces from penetrating into the hearts of cities to use them as defensive bastions. Evaluations of the edges of these cities could provide vital background information for the preparation of contingency planning.

In a similar vein, there is a need to know what urban features would be encountered in advancing into the core of the city from the periphery. Spatial patterns and building morphology characteristics need to be known, at least in a theoretical way, in order to know what to anticipate in an actual situation.

Finally, there is the comprehensive desire to attain a synoptic view of all of the environments which occur in metropolitan areas because it cannot be known what, if any, section of the city can be ignored, all environments

must be examined. And, not only must the characteristics of each element of the metropolitan area be known but the spatial relationships among them must be known as well.

5.6.1 Method

The concept of declining building and land-use densities from the center of a city outward is universal. Required is quantification of this concept to provide a base for making replicative generalizations to be employed in military planning. The accepted method for making these required measurements is to delineate features of interest on maps and then to measure and analyze these. This in turn involves determination of the spatial patterns encountered and measurements of the morphological characteristics of the urban features involved.

The following maps, diagrams, and tables (Figures 43 through 50 and Tables 19 through 21) are examples of various types of measurements of urban peripheral phenomena for several spatial and morphological characteristics. In the process, several measurement and graphic techniques are introduced.

The nature of the building types and their quantities which are found along a transect line from city edge to center is expressed in Figures 43, 44, and 45. Two views of the city are shown. In the upper is a gore from a concentric ring model. The lower is a profile of building height from city edge to city center. The height is in accordance with the scale on the left; the width (in both profile and gore) was determined by the amount of area of each building type in a city. The distance outward from the center was obtained by calculating the mean distance of all units of a type from the city center.

The establishing of meaningful generalizations on the patterns expressed would require the construction of 10 of these models. Some characteristics are, however, suggested in those presented. There are certain commonalities in the models of Casablanca and Bremen. Both have tall, "narrow" centers and both have wide areas of low, brick structures around the center. Both also have a blip of tall structures about halfway out to the edge and both have large areas of medium-height concrete structures at the periphery. Even though those two cities occupy quite different environments, both are products of European concepts and planning; Casablanca's extensive growth in this century is almost totally a product of French involvement at a time when Morocco was, in fact, an integral part of the economy of France. Both cities have large areas of brick apartment buildings lying just outside the center and both have areas of modern apartments of concrete construction located near the periphery.

These two cities are quite different than the graphed data for San Francisco which has, expectedly, a taller and more extensive commercial core. This core actually is composed of two slightly separated centers, the latter listed as steel (light clad) separated by an area of lower wooden and brick buildings. The height of the profile quickly drops off to one and two stories all the way out to the edge. Some of these structures are concrete tilt-ups, located in

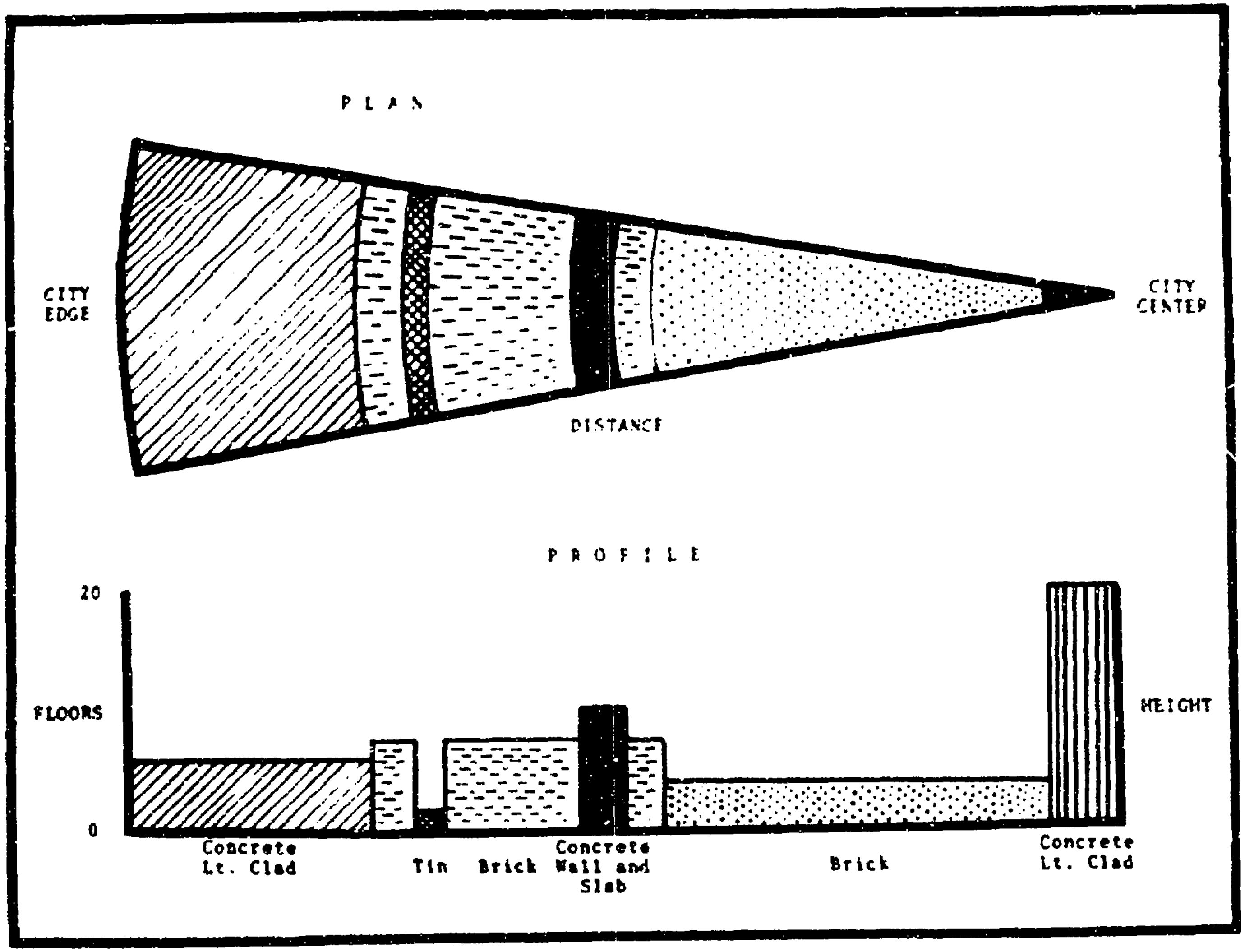


Figure 43. Building Type Location
Casablanca

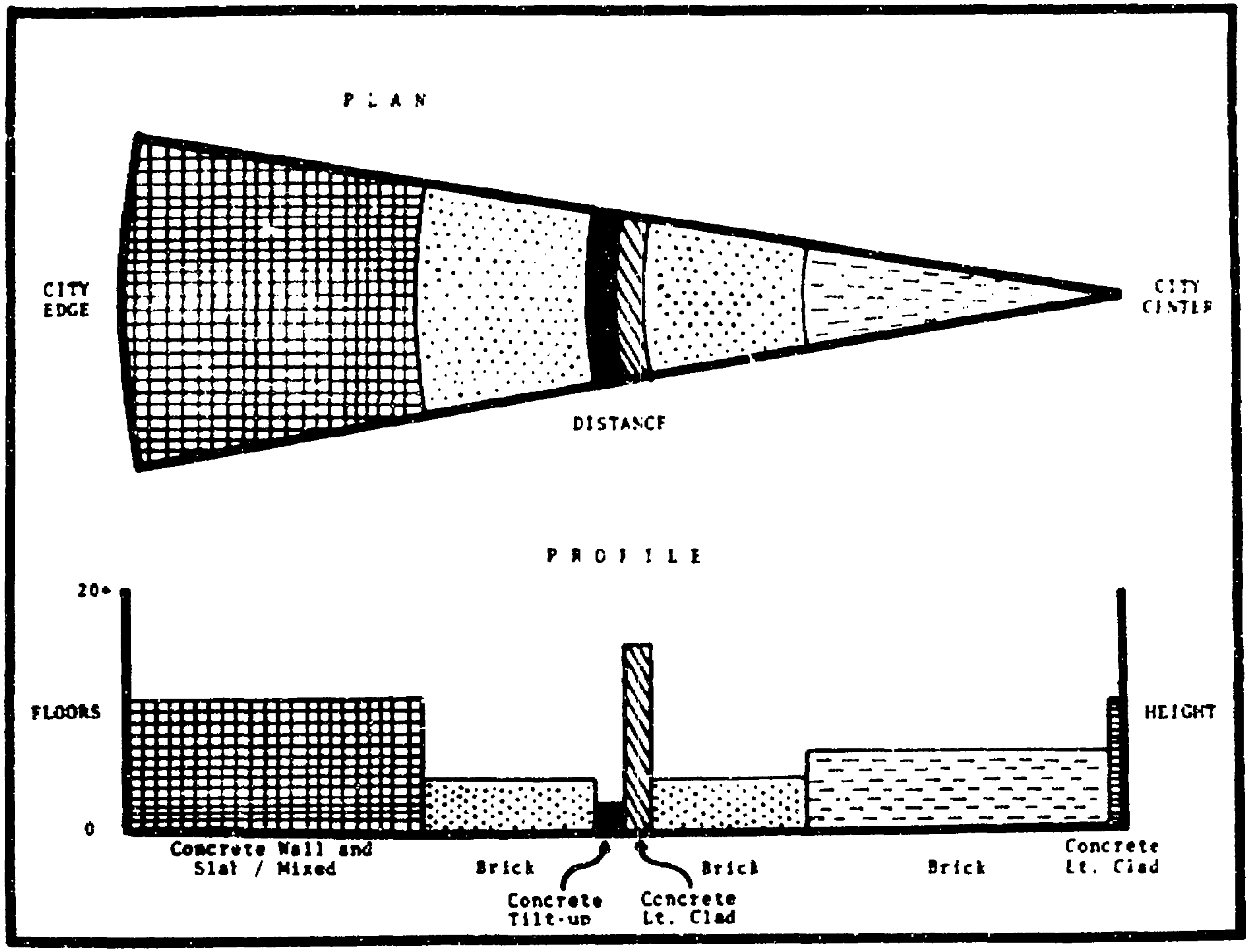


Figure 44. Building Type Location
Bremen

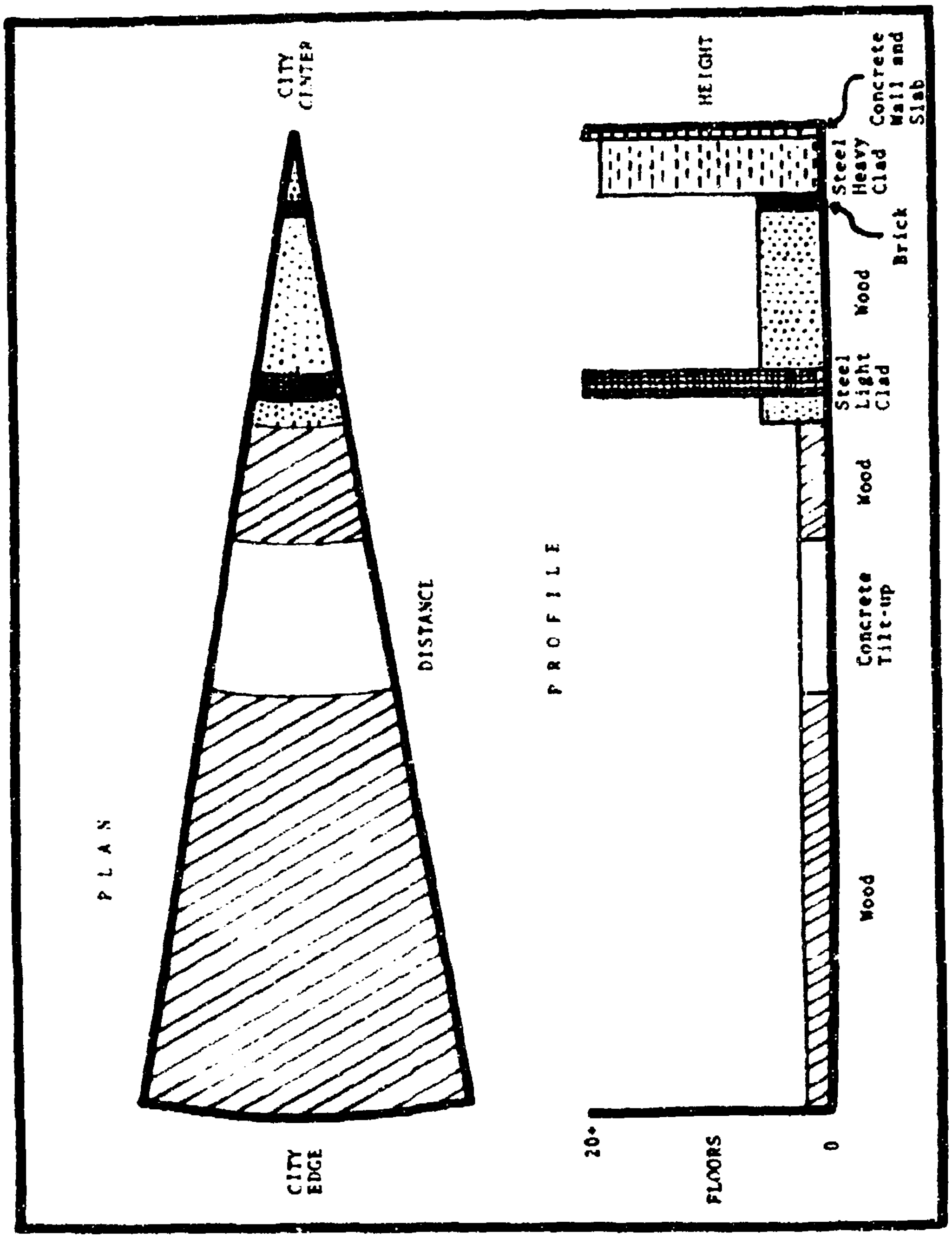


Figure 45. Building Type Location
San Francisco

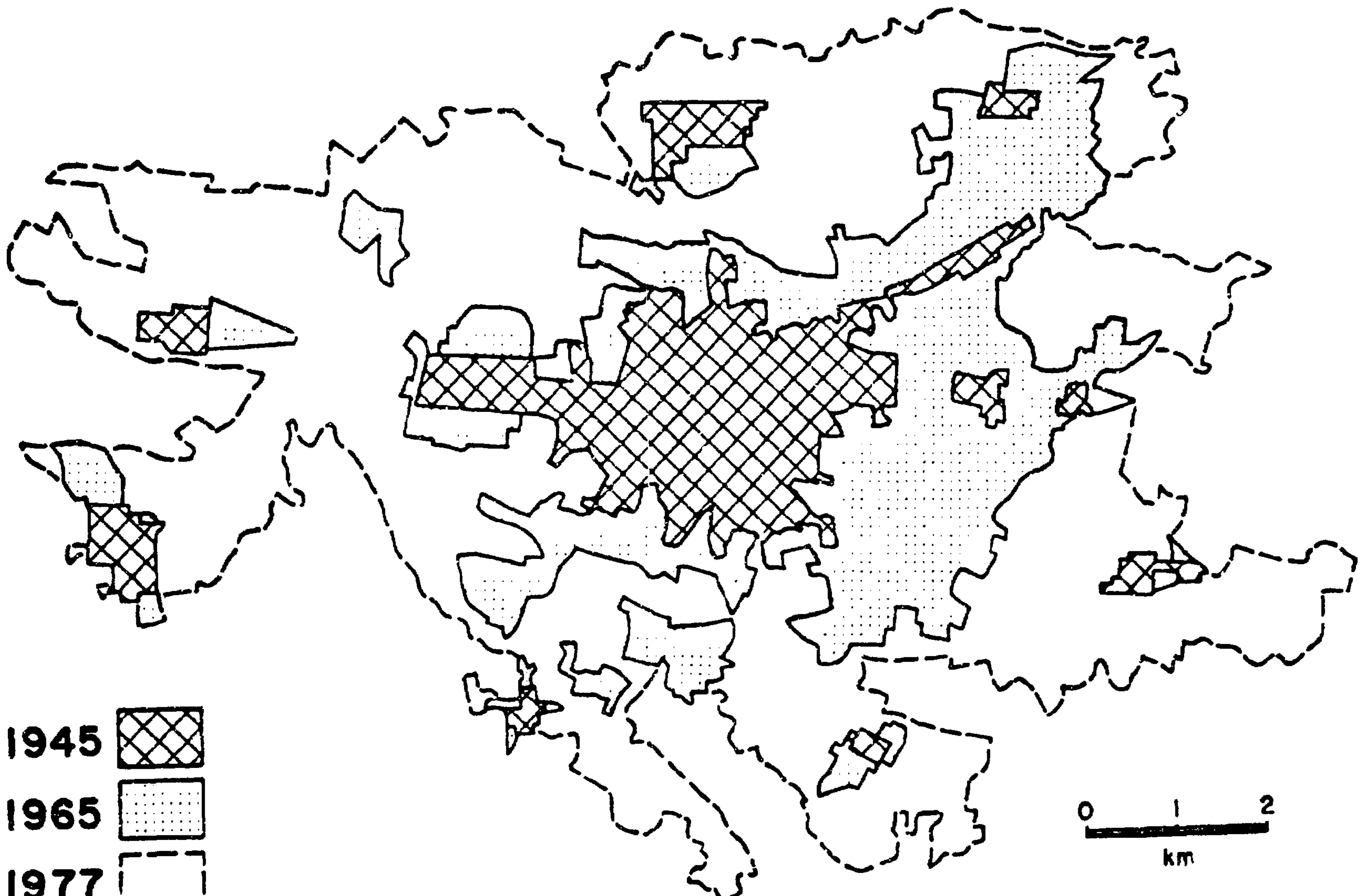


Figure 46. Expansion of the Urbanized Area
San Jose, Costa Rica

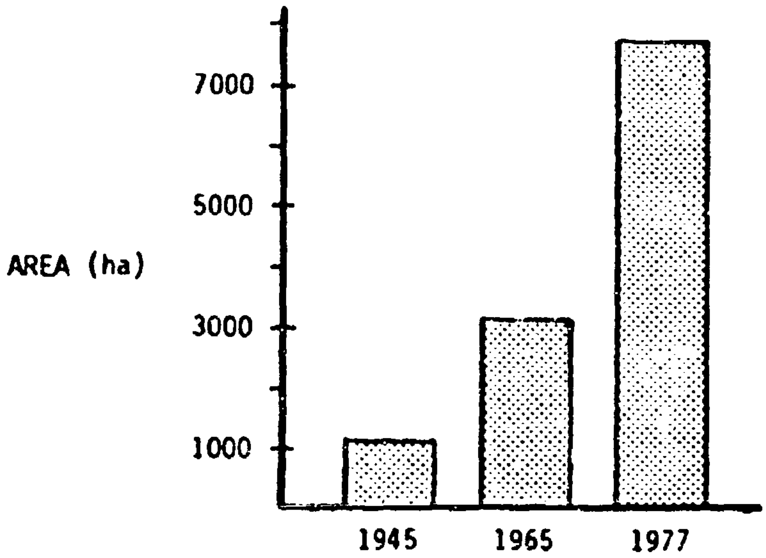


Figure 47. San Jose's Urbanized Area

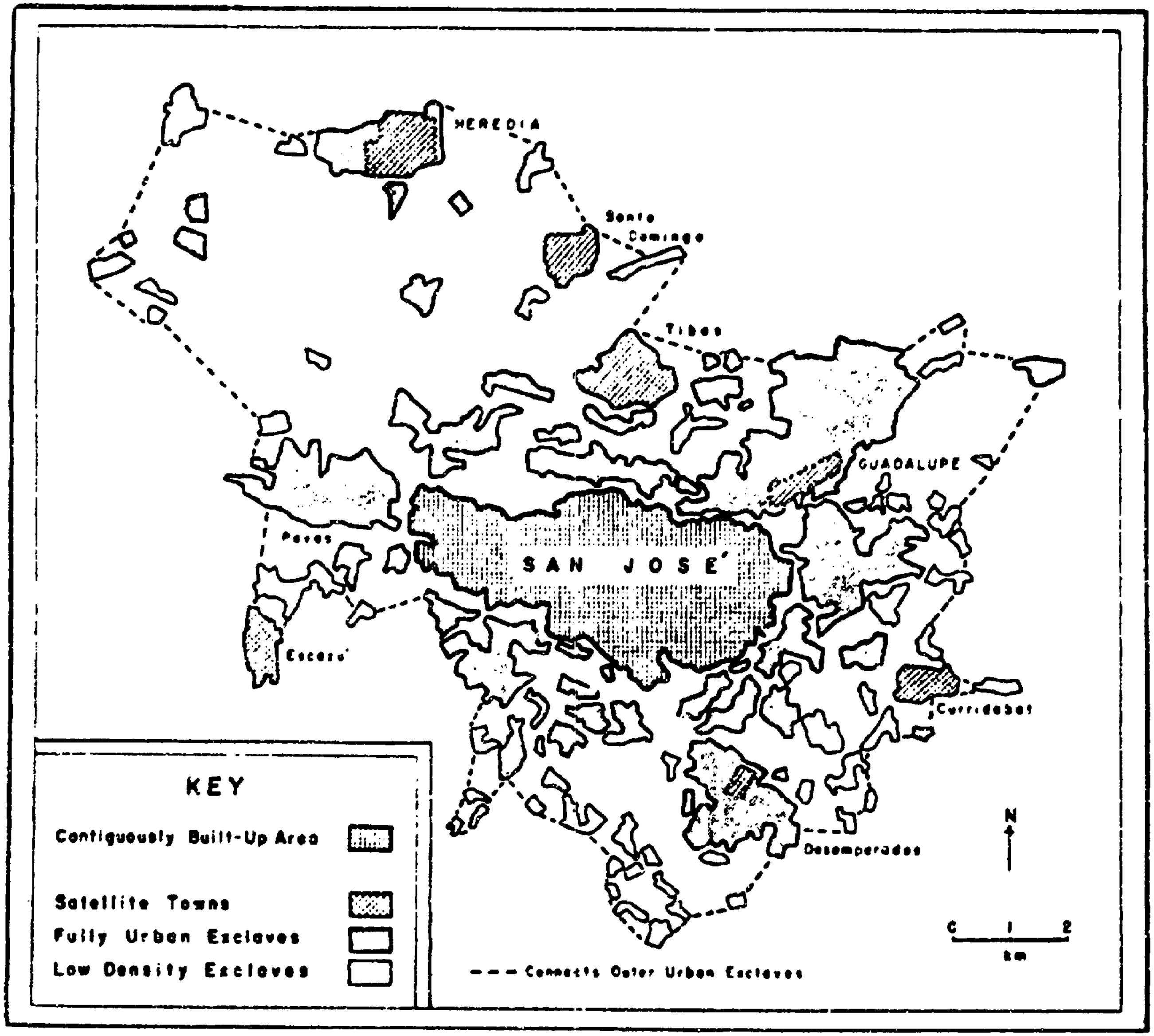


Figure 48. Contiguously Built-Up Area and Urban Exclaves
San Jose, Costa Rica
1978

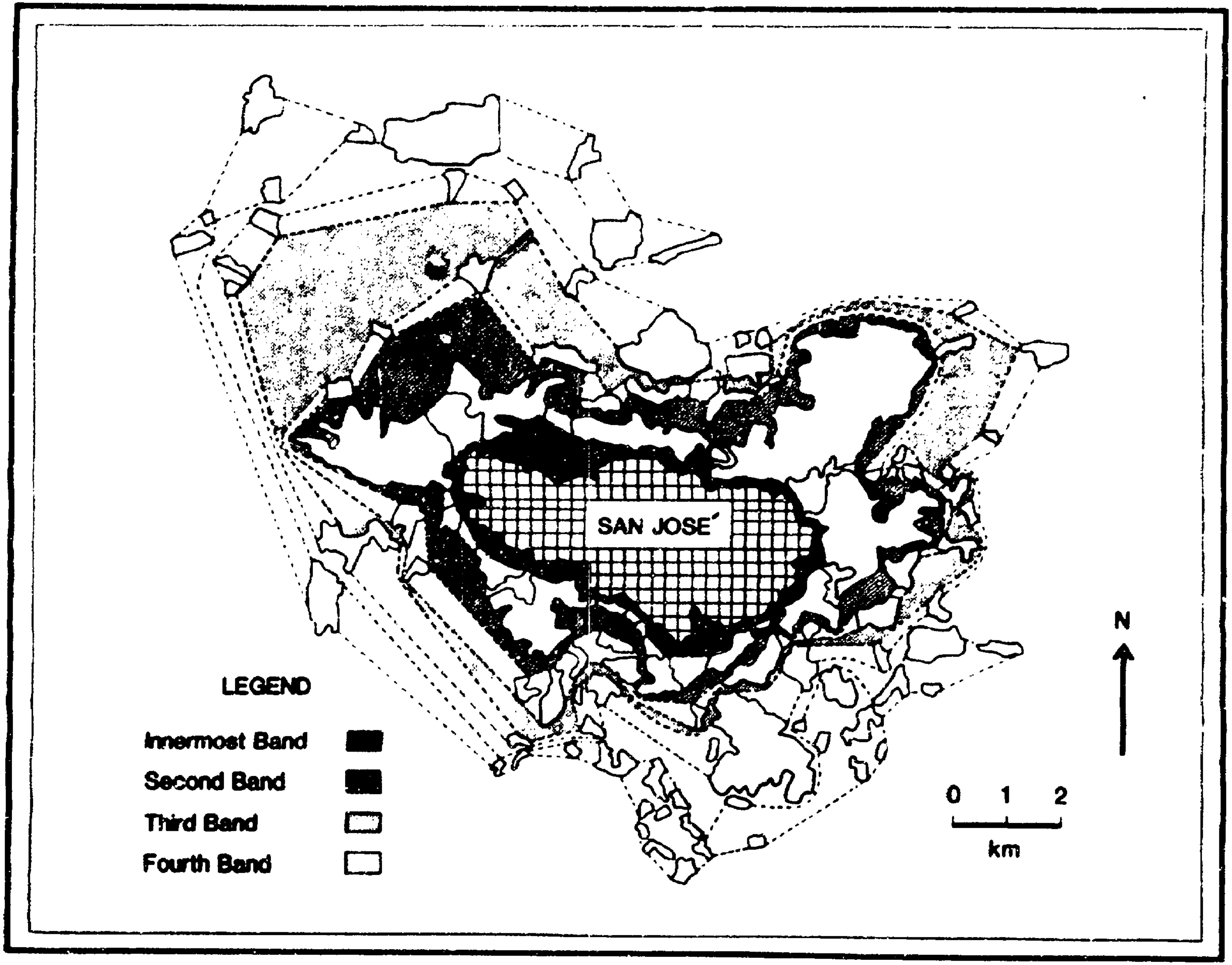


Figure 49. Bands of Open Space Between Rings of Urban Exclaves
San Jose, Costa Rica
1978

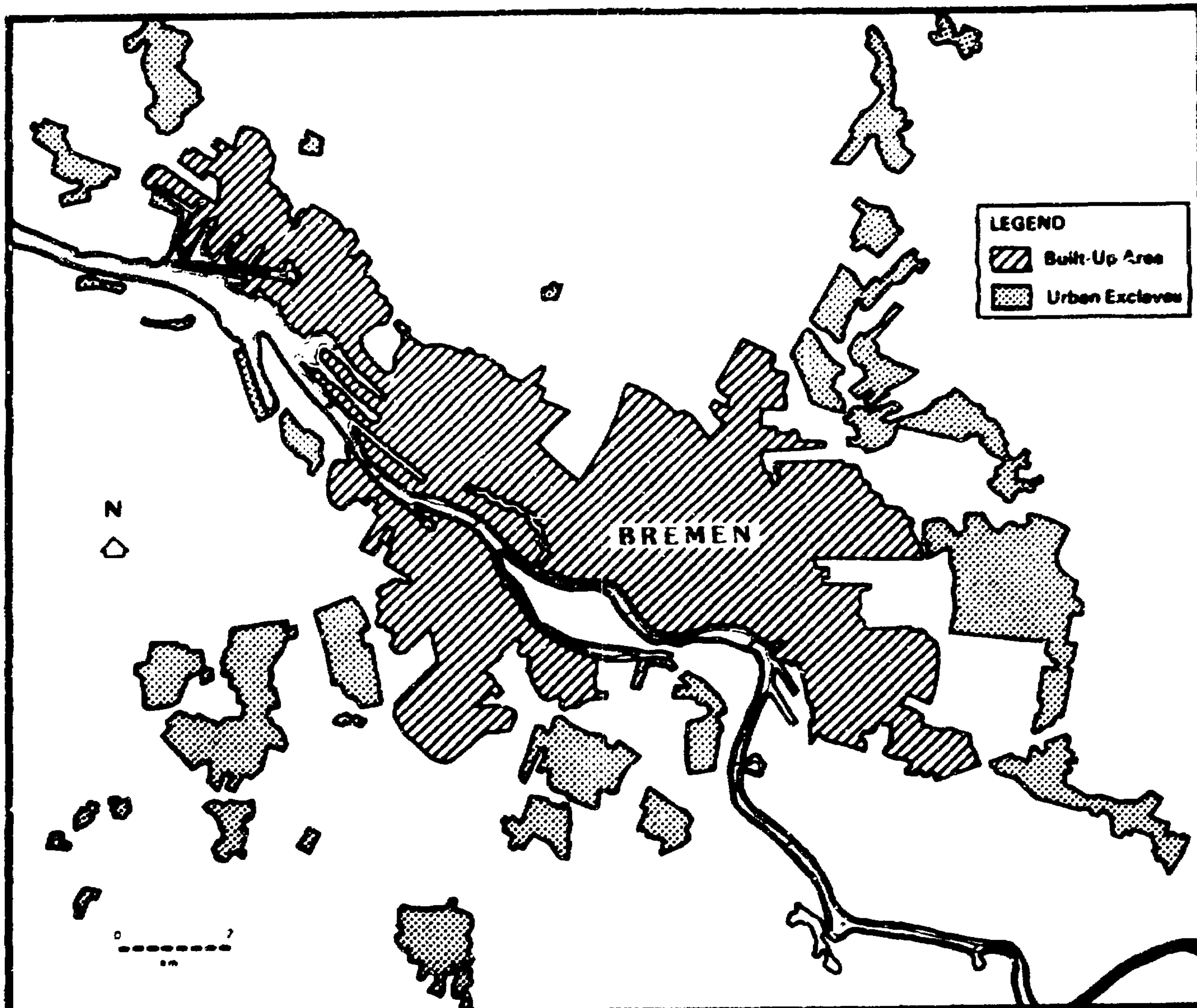


Figure 50. Contiguously Built-Up Area and Urban Exclaves
Bremen, FRG
1971

Table 19. San Jose's Urban Exclaves and Vacant Lands

1978

Type of Area	No.	Average Area (ha)	Total Area (ha)	Percent of Total
Contiguously Built-Up San Jose	1	-	1,379	8.3
Exclaves				
Satellite Towns	7	72	501	3.1
Concentrated Urban	48	57	2,752	16.6
Sparse Settlements	51	14	719	4.3
Exclaves Total	106	37	3,972	24.0
Vacant Land Among Exclaves Lying between Contiguous San Jose and Line Connecting Exclaves	1	-	11,213	67.7
Total	108	-	16,564	

Table 20. Pattern Analysis of
San Jose's Urban Exclaves
and Vacant Lands

1978

Measurements	Number of Exclaves	Total Area (ha)	Average Area (ha)	Percent of Total Area	Average Distance Outward (m)*
EXCLAVES					
First Ring of Exclaves	15	1769	118	46.6	263
Second Ring of Exclaves	25	487	19	12.8	1,720
Third Ring of Exclaves	23	754	33	19.8	3,104
Fourth Ring of Exclaves and Beyond	36	790	22	20.8	3,752

*Average distance of all units in ring from Contiguously Built-up San Jose.

Average distance between nearest neighbors = 268 m

Table 21. Spatial Characteristics of Contiguously Built-Up Area of Bremen and Its Environs

Type of Area	No.	Mean Area (ha)	Total Area (ha)
Contiguously Built-Up Area	1	---	5,182.5
Exclaves	33	89.8	2,964.2

A. Mean distance of nearest exclaves from contiguously built-up Bremen . . . . 615.4 m

B. Mean distance between exclaves (nearest neighbors) . . . . 547.8 m

industrial parks, but most are simply representative of the vast area of single-family residential sprawl which occupies such a large amount of space in U.S. cities. Such extensive coverage of the land is either precluded by a poor economy in the case of Casablanca, or by administrative decree in Bremen. The periphery of U.S. cities is always ragged and has lower building densities than is common in much of the rest of the world, although there are examples of U.S.-type urban sprawl in Latin America.

There is considerable potential military application of models such as these. The profile view is especially interesting to planners of air operations. They have a special need to know the height and location of tall buildings. Models help to develop generalizations about navigation hazards and potential sites for enemy firing positions. The gore models could serve a useful purpose for planners of both tactics and logistics.

5.6.2 Character of the Urban Periphery

The urban periphery is a dynamically and rapidly changing phenomenon because of extremely rapid growth which has occurred in cities throughout the world since World War II. A good example is San Jose, Costa Rica (Figures 46 and 47). During the period from 1945 to 1965, the urbanized area increased by some 21 km. The rate increased rapidly during the next twelve-year period (1965 to 1977) when the urbanized area added some 42 more km^2. Much of this growth was in the form of large planned urban units. Some were accretions to the existing contiguously built-up area, but many were in the form of detached urban exclaves lying from one to a few kilometers away.

Examination of the situation in 1978 (Figure 48) in San Jose, Costa Rica, reveals the nature of these outlying urban units. The satellite towns are older, well-developed communities. These have well-established, high

building-density centers and are but smaller versions of the old center of the central city. High-density ("fully urban") developments occur both at the edge of these old satellite centers and in isolated new developments. The term fully urban is used to indicate that they have building densities fully as concentrated as those of the central city. Many are planned, residential tracts with a full street network and have accompanying land uses such as shopping centers and schools. The low-density exclaves are those areas where houses have been placed, in a string fashion, along roads. While often facing one another across roads, the "urbanization" is only one house deep.

A fact of key military importance is the large number of exclaves (see Table 19). The presence of 106 exclaves for such a relatively small city is important if it is considered that these exclaves could, if fortified, form a formidible barrier to a force attempting to advance from the countryside to the city center. Also, they are large enough (at a 37 ha average) to form a considerable impediment. This is especially true when it is realized that they occupy positions along major access roads in and out of the city.

The line connecting the outermost of these exclaves contains a considerable amount of open area lying among the exclaves. This space has, potentially, both advantages and disadvantages. It is open area and thus allows more room for military hardware and troops to operate. But, it also represents open fields-of-fire for the defenders located in the exclaves. In a sense, the exclaves could perhaps be thought of, in the terminology of traditional fortifications, as "redoubts." The open space in between might be thought of as a series of "moats," or more provocatively, as areas of "no-man's-land."

The notion of exclaves and open space as "redoubts" and "moats" is amplified in Figure 49. In this map, the same data from the previous map were employed, but in this case an attempt was made to see if successive rings of urban exclaves could be identified. Lines were drawn to connect them and measurements were made (Table 20). As might be expected, the average size of the innermost exclaves was larger than those farther out. These units are older and thus more completely developed. Exclaves in the second, third, and fourth rings were more nearly the same in size, reflecting their character as housing developments and the like.

A figure of some significance is the 268-m average distance separating all exclaves. This suggests that, on the average, virtually all of the open space among exclaves is within range of even small arms fire.

A final characteristic demonstrated on the map is the shape and size of the rings of open space. While this is a contrivance from reality because of the presence of other open space between the exclaves, it does serve to show something of the nature of the fields-of-fire to be anticipated. The local variation on urban growth has caused there to be very narrow bands on the southern and eastern sides of the city (those parts developed first) as opposed to the wide bands to the west side where large new urban exclaves are currently under development. The delineation of spatial data of this sort for a wide variety of cities would result in the identification of regional types. They could then serve a supportive role to military planning.

Comparison with one other city, Bremen, (Figure 50) illustrates the strong contrasts possible between cities of one culture and another. European city planners have been much more restrictive, generally, than their counterparts in the U.S. and Latin America. Agricultural land in Europe has been held to be inviolate and is not considered as a commodity from which a quick (and final) profit can be made.

Examination of the mapped patterns for Bremen, (Figure 50) and San Jose, Costa Rica, (Figure 48) demonstrates the point. Urban development in the rural hinterland of San Jose has occurred so rapidly and to such a high degree that the total area of exclaves (3,972 ha) is nearly three times that of the contiguously built-up area (Table 19). For Bremen (Table 21), by contrast, the contiguously built-up area (5,183 ha) is far larger than the exclaves (2,964 ha). Not only is the exclave area large in total but the average size for Bremen, at 89 ha, is larger than San Jose's 37 ha average. Mean distance of exclaves from the contiguously built-up areas and mean distance between exclaves (nearest neighbors) is fairly close.

The military implications are clear. Cities with a looser control of peripheral growth, such as San Jose, provide far more potential impediments to ingress than would be true for cities of the Bremen type. There are more "redoubts" and more open fields-of-fire controlled by these. On the other hand, the more solid phalanx presented by the outer boundary of urbanization by a Bremen-type city could be addressed by a variety of weapons systems including armor, artillery, and aircraft all operating from within the open countryside.

6.0 CONCLUSIONS

The conclusions reached result from: (1) intensive study during the contract period, (2) preparing and delivering reports of findings to NSWC, (3) meetings of the Military Operations Research Society, and (4) conferring formally and informally with colleagues in the MOBA community. Much of the study has been exploratory and accordingly, some of the conclusions are tentative. Most, however, are positive. Other tentative conclusions, for subjects as yet not fully explored, are given with certain caveats.

Conclusions are arranged in accordance with the chapter outline of the study; each section is preceded by comprehensive conclusions. Subheads indicate the areas. Application of these conclusions has led to the formulation of a series of recommendations which appear in the following chapter.

6.1 COMPREHENSIVE CONCLUSIONS

The most general finding and conclusion is that the study items specified in the contract are of vital importance to MOBA interests. These items address key questions concerning the urban environment as a potential locale for military operations.

Most important is the overall consideration that urban buildings should not be treated out of context. While the study does examine the physical characteristics of buildings in detail and presents these in proper analytical format, a greater gain is achieved by relating all buildings to their immediate environment. Thus, the dimensions of streets or squares on which building are located need to be known in order for military planners to prescribe appropriate weapons and tactics.

The conclusion is reached that the organization of the study serves, as well as possible at this time, to meet these needs. The architectural details in Chapter 3.0 provide necessary information on the relationship of building style to such characteristics as venting and interior arrangements. The data offered on walls and partitions in Chapter 4.0 are required as background for weapons design and testing and for tactics development. The findings in Chapter 5.0 on spatial patterns provide a base for what could be extremely important work in the next phase of MOBA considerations.

The second major comprehensive conclusion is that more emphasis should be placed on observed and measured universality among cities of the world than on local differences. Although certain local distinctiveness in architectural form occurs due to the use of regional building materials, construction techniques, customs and traditions, these are but local variants of more general building design parameters. The greatest variation is seen in construction of detached housing, an enterprise which closely relates to local customs and modes of living.

First, among the conditions which support the notion of universality, is the need for all buildings simply to stand and to resist vertical and horizontal stresses successfully as well as providing protection from the elements. In addition, a very high proportion of all buildings in cities of the developing world have either been built by European or American firms or their design and construction have followed standards set by developed nations.

A second universal parameter is that buildings are constructed to serve but a relatively few types of functions and that design and constructional types are in accord with the intended function wherever buildings are erected. Examples are: high-rise office structures all of which conform to certain standards in their provision of interior space for office functions; hotels everywhere are concerned with providing uniform size guest room space; and warehouses serve storage functions.

In addition to the functions of individual buildings, functional zones within cities demonstrate nearly the same characteristics everywhere. The binding principles of such things as access to rail transportation for handling industrial and storage functions and the requisite agglomeration economies which obtain for retail establishments in central business districts are also everywhere applicable. As one example, space devoted to the public sector in the form of streets is invariably small in downtown areas where land values are the highest found anywhere in the city.

A third universal parameter is the desire and need to be cost-effective in building. This is obvious, considering that provision of space is but one of the costs of doing business. For modern construction particularly, structural engineers have identified minimum safe levels of strength required to serve particular needs and they generally do not prescribe using material and methods which exceed these levels.

The third comprehensive conclusion is simply that in the course of conducting this study several gaps in knowledge of the city surfaced. If military planning is to be conducted which will allow for all the possible manifestations of urban fighting, numerous aspects of cities must be examined in detail. Conclusions must then be drawn from these and placed into a program comprising such important military considerations as weapons design and testing, tactics and doctrine development, and logistics and communications planning.

6.2 CONCLUSIONS ON ARCHITECTURAL CHARACTERISTICS

Several conclusions were reached. Some emerge from the measurements made; others concern methodology and approach to the subject.

The most comprehensive conclusion is that the distinction between framed and frameless buildings offered in the first report, Urban Building Characteristics, is sound and has several advantages. First, it has the valuable quality of establishing in words the significant distinction (for military purposes) which exists between the thick, load-bearing walls of the frameless

structures as opposed to the implicitly thin walls of the framed structures. Considering the current importance attached to the necessity of breaching walls, this distinction is highly valuable. Second, the considerable number of field observations made in several countries by the author in and since the last study confirms that the classification system works with real-world cases. Further, the system has the desired attributes of being simple and direct. These are absolutely essential when in the field with all of its inherent distractions of traffic, street activity, and signs. In practice in the field, the basis of the system--frameless or framed--is applied as a first test. The clues developed in the earlier work are then applied in a verification procedure. Once the basic distinction has been made, other clues are entered into the classification procedure to place a given building more discretely.

The second major conclusion states that there exists everywhere a binding relationship between a building's morphology (structure) and its function. Dismissing the conversion of older structures to some function other than that for which they were intended, buildings everywhere were designed to serve a particular function and selection of the most appropriate form of construction for that function was involved in all cases. Thus, wall and slab (box-wall principle) structures are used for human habitation such as hotels and apartments, concrete-framed buildings are used for offices, stores, etc., and tilt-ups are used for storage and light industry. Some variations do occur, depending on local costs and available technology. For instance, concrete framing is used for the construction of warehouses in countries where labor is low cost and tilt-up techniques are not available.

The relationship between morphology and function also manifests itself in several particulars concerning buildings. For one example, the form of venting on the one hand reflects what is possible with a certain style of construction and on the other on the needs of the intended function. Arrangement of building interiors is another example. The setting also shows a relationship. Buildings for light industry are usually set apart from one another in order to provide needed space for outside storage of raw materials and finished products.

Another conclusion related to function is the universal occurrence of broad venting at street level for buildings facing commercial streets. This comprises most of the streets in a downtown area plus outlying business arterials. An awareness of this phenomenon has a potentially very significant impact on planning for such possibilities as the use of shoulder-carried assault weapons. For a large part of the downtown area, at street level, there is little requirement for wall breaching.

Yet another conclusion on the relationship between morphology and function is the accord noted which exists between building exteriors and interiors. By "reading" the character of the exterior, it is possible to predict with a high degree of probability the nature of the interior. This "reading" requires placing into proper context observed information on both structures and function. In looking at a hotel, for instance, after having identified its structure as being (in this case) a heavy-cladded steel/concrete-framed structure

and observing the pattern of the windows and determining that there is one per guest room, it is but a matter of reason to infer the arrangement of these rooms and the articulating hallways.

Of further import is the fact that building interior designs are made in accordance with certain standards prescribed by building designers. Reference books, compiled for the use of these designers, specify such critical facts as the number of square feet desired for all possible room functions. Guest rooms in hotels, offices designed to accommodate x number of workers, and required space to conduct business and industrial functions are but a few examples. Further, there is very little deviation from these standards anywhere in the modern world.

Another conclusion concerns the incidence and importance of buildings facing street intersections. In numerous observed cases, buildings at street corners have angled facades, that is, at 45-degree angles. The architectural goal here is to break the harsh appearance of squared corners, to enhance building style in an otherwise lackluster setting, to provide more light for large corner rooms, and to provide a ground-floor entrance which is more attractive to potential customers than an ordinary corner. The greater field of view possible from such corner positions overlooking the intersection is potentially of key importance in planning for military tactics.

The conclusion states further that such corner situations are found both in frameless and in framed buildings. Origins are related, however, to masonry structures which incorporated structural strength with design, as is discussed in the main body of the text.

6.3 CONCLUSIONS ON WALLS AND PARTITIONS

Conclusions about such physical things as walls and partitions are derived from evaluation of measurements of their dimensions. Taken from published sources in part and from field observation in part, the body of data is well defined.

A primary conclusion is that, for the materials identified in the early report, a definite order exists. Brick walls, for instance, are constructed in virtually the same manner everywhere with the only variables being the dimensions of the bricks employed and the form of bonding used. Adherence must still be given to standards of thickness to maintain structural integrity. The rule is followed everywhere that such mass-constructed walls must be thicker at the base than in upper floors and that progressive rates of thickening are followed with increasing building height.

Universals also obtain for cladding of framed buildings, both heavy and light. Even though such cladding is not weight-bearing, it still must provide a certain stiffening (for the heavy-cladded steel-framed buildings) and must adequately protect against the weather. Accordingly, their composition and thicknesses follow certain prescribed levels. A subconclusion, and a somewhat tentative one, is that an increasing number of the newest concrete-framed

buildings have had a fairly heavy cladding applied to them. The reasons are partly for style and partly to make these buildings more energy efficient whether that be for retarding heat loss or gain.

Another major conclusion is that knowledge of the city has now reached a point where it is possible to determine the extent of wall breaching which might be necessary in MOBA activity. The proportion of walls to windows is recorded in the text for a wide variety of buildings. Interaction with the known locations of these buildings (from the previous study) can produce the kind of information needed by tactics planners to estimate just how much breaching might be necessary in an actual combat situation. The tentative offering is that not as much breaching is required as had been previously thought. This is so in part because of the high proportion of glazing in the downtown areas. In addition those mass construction buildings, such as concrete-walled factory and warehouse buildings in outlying sections of the city are generally found in settings which are open enough to permit the use of some other weapon such as artillery, armor, or air support.

The greatest requirement for wall breaching might well come in areas just outward from the commercial districts of cities in such areas as apartment buildings, with their small proportion of glazing, or in certain warehouse and light industrial functions located at the edge of the central business district. Yet another need is where windowless sidewalls of buildings have been exposed after neighboring buildings have been razed. Or, there is a potential need for breaching through sidewalls in going from one building to another.

Concerning building interiors, there is the conclusion that partitions, as is the case with exterior walls, demonstrate an order in dimensions and in the nature of materials used. These are universal in response to the need to accomplish the task of enclosing interior space in the most cost-effective way. All are reasonably light in construction and easily penetrated.

6.4 CONCLUSIONS ON SPATIAL PATTERNS

Conclusions here reflect the concern of the chapter for examining and measuring the spatial patterns of urban features. Represented here are conclusions, or generalizations, derived from looking at the configuration of the city in new ways. Conventional studies offer little guidance.

The basic conclusion is that there are identifiable and measurable spatial patterns within the city and that they display an observed order. Measured factors include such obvious things as street widths and the not so obvious networks of open spaces and the peculiarities of lines-of-sight and angles of obliquity. Militarily useful generalizations result when these measurements are aggregated and analyzed.

The more specific conclusion concerning line-of-sight is that a definable and replicative order exists for each functional-cum-morphological type of area. Thus, average lines-of-sight are generally uniform for such functional/morphological areas as central business districts, wholesale/light-industry

areas, and various types of residences. It is of special value to note that little variation is seen among cities everywhere, especially within a single cultural/economic region, e.g., the Middle East.

A related conclusion is that there is a high degree of order connected with the phenomenon of open space within the city. Regardless of the region of the world, open spaces occupy about the same proportion of total space for all cities, are about the same size, and occur with about the same spatial frequency. The obvious inference to be taken here is that these open spaces have a pattern which may be relied upon as a constant in military planning. Their potential as staging areas and suitability for air operations is high. They also come into play in consideration of fields-of-fire.

Continuing the theme of line-of-sight analysis, evaluation of measurements made in the study confirms that an order exists for both along-the-street and across-the-street line-of-sight distances. Street widths and patterns of street configurations are related to functional and morphological zones within the city. They achieve this universal order because of the nearly similar response everywhere to such stimuli as the desire to obtain maximum utility of surface space. For example, street widths in downtown areas are as narrow as possible to save high-value space for buildings. Street configurations are the product of planning (or the lack of it) at various periods in history. Curving streets result in one instance from a haphazard medieval development and from another in a modern suburb planned with aesthetics and traffic control primarily in mind.

A special finding comes forth from the study concerning the potential utility of a shoulder-carried assault weapon in concentrated sections of the city. In a hypothetical case, where street widths are narrower than the minimum arming distance and where a limit on angle of obliquity is established, it emerges that there are some sections of some cities where such a weapon could not be used. Not, at least, without making certain modifications such as firing at a target across the street from an enclosed room or from a rooftop location.

Another broad area of conclusions concerns the vast area of the peripheries of cities. A general conclusion is that the pattern of outlying developments, outside the contiguous mass of the city, varies regionally. Countries which exercise little control over urban development in the countryside (including the U.S.) have numerous isolated urban exclaves lying just beyond the main body of the city. Other countries, with a standing tradition of not violating food-producing adjacent agricultural land, have restrained such developments. Germany, the study example, has allowed only controlled developments and these are primarily accretions to the already built-up area. Some outlying conversion of land use from rural to urban does occur, however, and these often result in the tying of existing rural villages to the main body of the city by string development along roads. And, in some instances, in response to a high demand for single-family housing, housing tracts have been allowed to be built in the countryside.

A tentative conclusion is that a knowledge of these peripheral patterns could serve useful military purposes. Avenues of approach to a city must

consider the existence of outlying urban exclaves. These exclaves could well serve as "redoubts" in a defensive posture. By definition, they often sit astride major avenues of traffic and communication. Between these islands of urbanization are open areas which must be crossed in moving on a city. That such open areas may be hazardous needs to be considered.

A further tentative conclusion concerning these urban exclaves is that they exhibit some sense of replicative order, at least within regions. Further study is required for confirmation.

7.0 RECOMMENDATIONS

The recommendations offered here are a natural outgrowth of the conclusions which, in turn, were based upon an evaluation of all of the data presented in the study. The recommendations are placed in the three groups of (1) full consideration of all aspects of the urban environment, (2) weapons development and testing, and (3) tactics planning and design.

7.1 FULL CONSIDERATION OF THE URBAN ENVIRONMENT

Responding to the original stated need to learn more about the nature of walls in order to know what was required to breach them, this study and the previous one produced information on wall composition and dimensions. In making the required investigation, however, it was discovered that large areas of walls as potential targets do not occur everywhere in the city. Accordingly, it was concluded that they may not present the degree of problem that was originally envisioned.

This is not to state, however, that wall breaching would not be required in a MOBA operation. Rather, the specific recommendation is offered that there is a need to be able to estimate just how much breaching could be necessary and where within the metropolitan area this would occur. We already know the general locales. In downtown areas these would be in instances where solid walls have been exposed or where it might be desirable to penetrate the sidewall of one building from within another building. In areas outside the downtown, larger, unvented wall surfaces are associated with nonbusiness functions, such as apartments and warehouses. Thus, there is a need to manipulate data thus far gathered and add enough extra data to be able to plot on maps of test cities the areas where the highest probability of wall breaching would be necessary. This information would be extremely valuable to MOBA planning in general and in particular to weapons design, tactics planning, and logistics planning.

A subdivision of this recommendation is the suggestion that the nature of the setting of buildings should be examined relative to the difficulty of breaching their walls. That is, for each type of construction there proves to be a recognizable spatial pattern. For example, many modern high-rise buildings are free-standing, not abutted to their neighbors as was common earlier. Brick buildings, by contrast, are usually on fairly narrow streets and touch each other as they face the street. Close examination of these situations could produce spatial data (in map and tabular form) which would aid military planners in handling problems of minimum arming distance, warhead capability, and angle of obliquity.

Another recommendation is that full consideration should be given to the remarkably replicative patterns associated with open spaces. Their number, proportion of space occupied, size, and placement are so nearly uniform that some practical use of this phenomenon can surely be made.

It is further recommended that the information provided in the report on line-of-sight distances, both along and across streets, be fully implemented in the planning process. The two figures might be used in tandem in the creation of an index of difficulty of operations. Application of the method developed to more cities in general and to key cities in particular could well be a wise investment.

The findings obtained from examining test cases of urban peripheries should also be placed into the military planning process. In particular, the concept of urban exclaves serving as potential fortified "redoubts" could have merit and should be pursued for more cases. Related is the problem of the intervening open spaces which would have to be crossed in advancing upon a city. The degree of hazard, or opportunity, these might present, deserves investigation. Such data as the distances across these open areas could be placed into a military use context to address problems of range, armor movement, potential air operations, and cover for infantry. Of particular value would be examination of enough additional cities, representing various regions of the world, which would lead to the development of regional types. Such information could be especially useful to USMC global planning.

In a similar vein, another recommendation would be the use of the gores and profiles of modeled situations in the study as an aid in planning for ingress and egress. Potential users of this information are both ground forces and air-support forces. The generalized format of the data would serve well for master planning and for generalized training and doctrine development.

A final recommendation on the spatial character of the city concerns the examination and consideration of the phenomenon, revealed in the study, of the shape of buildings at street intersections. While only a minor variation architecturally, awareness of this situation could be very important to movement of personnel and vehicles along city streets. While the nature of the phenomenon has been identified here, there is a clear call for making absolute observations in the field in key areas and producing charts which would reveal the cones of vision and fire. Further analysis would lead to the flagging of areas of greatest hazard or possibility for both offense and defense.

7.2 WEAPONS DEVELOPMENT AND TESTING

Evaluation of the data in the report leads to the following recommendations concerning such aspects of weapons as minimum arming distance, angles of obliquity, firing positions, warheads, sights, and right-hand versus left-hand usability.*

The general recommendation, as seen clearly from the study, is that weapons should be tested in as realistic a simulation of real-world urban situations as possible. This recommendation is broken down into the two subdivisions

*Capt. Adolph Carlson, USA, from the Infantry School, Fort Benning, has studied this problem in detail.

of (1) testing against all types of targets, and (2) in all types of environmental situations.

Looking first at targets, it is recommended that the following test activities be conducted. First, all the types of walls described and measured in the study should be made into simulated targets, and test firings against them should be conducted. This recommendation is broadened to include a variety of weapons in addition to the shoulder-carried assault weapon. The result of such testing would be to match the tool to the task; the weapon to the wall material. Thus, test firings should be made against the various thicknesses of mass walls and the various types of cladding for framed buildings. For the former, thick stone walls might either be ignored--because of their rarity--or simply relegated to heavy weapons. Brick wall targets, though, should be constructed in thicknesses ranging from the "three-brick" wall (3 headers) to a "five-brick" wall. Respective thicknesses are 30 to 50 cm. Considering further that most bricks outside the U.S. have a larger unit size, the recommendation is that targets be constructed with "four-brick" walls having a total width (including mortar) of approximately 45 cm. While constructing such target walls is expensive, these widths are common for the great number of multistory brick structures which are found so widely virtually everywhere in the world. The thinner walls (the 30-cm variety) also need to be tested as they would come into play in the vast brick structure residential areas of the world's cities.

Concrete walls are also important. They occur in reinforced mass construction forms of several types of buildings and are universal in their occurrence. The thicker, more heavily reinforced ones are found in mass-construction (load-bearing) buildings. Here, thicknesses reach 25 cm. Lighter ones, in the wall and slab structures and the tilt-ups, are as narrow as 15 cm.

Reinforcement bar thickness and density vary widely and are prescribed in response to anticipated building loads. Conservative testing, however, would suggest that bar thickness be as large as number 5 (5/8ths of an inch) and that densities be at least 10 in. centers. A single mat, placed in the center of the wall, is considered to be sufficient for walls up to 20 cm thick but for those beyond there should be a double mat, each placed just beneath the outer and inner surfaces.

A major concern uncovered in the course of the study, however, is the recognition of the potential difficulty posed by the various forms of cladding on framed structures. First, in keeping with the large proportion these structures form of all buildings, any problems posed by these walls is common and universal. Second, the strength (resistance to penetration) of these walls could be greater than had been previously realized. For example, the variety of materials employed in the making of heavy cladding walls of the early steel/concrete-framed buildings could present a problem. It is recommended that walls of this sort be constructed and fired against to determine just what effect the combination of bricks, insulation, hollow tile, and interior finish material have on various projectiles. A further concern is the thicker than anticipated aggregate concrete cladding being placed on many of the new concrete-framed buildings. Although not load-bearing, they are nonetheless as thick as 20 cm, not counting layers of insulation and inside surfacing materials.

Furthermore, since many of them are placed at angles other than parallel with the street (for decorative purposes and sun shading), they present unusual angles of attack when viewed from street levels. Simulation testing could be valuable to determine such characteristics as deflection.

Consideration in a testing procedure should also be given even to the lightest of the light cladding materials. It would be interesting to know the effects of thin materials (glass, plastic, insulation, metal) placed together, as they often are, in composit combinations. What tools are required to penetrate them, what happens to the projectile, and what damage ensues are questions which could be answered.

Another recommendation involves building venting and its relationship to weapon testing. (Reference should be made to tables in the text which provide the proportions of the exterior walls of various types of buildings which are vented.) First, awareness of the amount of nonvented wall (and not part of the frame for framed buildings) is useful in knowing the amount of wall surface to consider as a target. Second, since these proportions vary with function as well as structure, the application of functional zone models to cities can serve to flag in advance locations within cities of potential wall targets.

Another value of data on window venting relates to weapon sighting. The absolute and relative sizes of windows and related angles of obliquity have a bearing on the ability to hit them, presuming they could be targets.

It is thus recommended that a variety of window and door types be set up for test firing purposes. Ideally, windows should be placed both at ground-floor level and for one or two upper floors as well in order to evaluate best the problem of the vertical aspect of sighting.

A related suggestion is the possibility of building multistory test buildings in which the floor/ceiling of a floor above is visible through a window on the floor below. Test firing could then be conducted through the window with the intent of hitting the ceiling (floor of the story above). Composition and dimensions of these floor/ceilings are known and could be used in the design of such a target.

A type of target which has received little attention thus far in MOBA considerations is the interior partition. By definition, of course, these are easily penetrated; the term wall breaching hardly seems appropriate. Yet, if troops were to be engaged inside buildings, the need for moving from one room to another could very well require going through these walls. Again, materials and dimensions are provided in this study and could be used to construct targets. It would seem valuable to establish the most cost-beneficial means to accomplish the task.

The second major area of concern falling under the heading of weapons testing is that of giving full consideration to the nature of the environment in which particular types of targets are found in real-world situations. For example, firing at brick buildings should be conducted in the kind of environment in which they are most commonly found. For instance, these buildings are

commonly located along narrow streets. This being the case, there is a call for firing head-on from distances of not more than 25 m. In addition, high angles of obliquity are the rule and firings should be made which test these. Similarly, all building types have associated environments suggesting a variety of firing distances and angles.

A recommended general technique to approach the problem would be to conduct a controlled test covering the whole range of relationships between minimum arming distances and angles of obliquity against all types of targets. The findings could then be matched to probable occurrences of all possible situations in reality.

In a similar vein, ranges and accuracy should be tested invoking along-street horizontal lines-of-sight; the parameters again being derived from real situations. A possible result may be that characteristics of warheads and propellants could be matched to different types of situations.

Another area of common concern in MOBA, that of firing from within rooms, should be addressed in accordance with data supplied. As has been demonstrated, in the narrowest of city street situations, there are instances when a shoulder-carried assault weapon might not be able to be used at all from the street. An approach to the problem would be to invoke the cones of possible fire (examples of which are demonstrated in this study) into a model which would determine the number of possible firing positions possible for a given situation. These findings could then be related to known average room sizes to determine if within-the-room firing was possible.

7.3 TACTICS PLANNING AND DESIGN

Many of the characteristics of the city brought forth in this study have broader potential application than just the design and use of a single weapon. Many of these characteristics are spatial in nature and can be related to the general field of tactics in which all manners of tasks and solutions are involved. A number of recommendations can be extracted from the nature of cities as inferred by evaluation of the data.

A general recommendation is that the models of city characteristics should be employed in devising means for either advancing upon a city or defending it. A knowledge of such broad characteristics as the existence of rings of brick buildings surrounding the core could be employed in such planning. The network of open spaces is another.

Several specific recommendations are offered as well. One concerns the employment of data on the configurations and dimensions of building interiors demonstrated in the study. These plans, considered relative to their incidence of occurrence, could be used in theoretical planning and for the construction of table-top models and training centers. Simulations of buildings actually found in cities would seem desirable to achieve maximum reality in training.

A by-product of the above could be the development of means to move laterally from within one building to another. The customary features from reality, such as fire walls and doors, could be simulated.

Another recommendation stemming from observation and from data in the study is the consideration of the effect of light cladding on both defensive and offensive situations. The large amount of this material and its probable capability to withstand light fire suggests that it could possibly be a significant factor in MOBA situations. Composites reflecting architectural and structural forms currently in use could be simulated for training purposes. A related question is the amount of rubble which such material could create. Its use in a defensive posture should be evaluated.

A final tactics recommendation concerns the avenues of approach to the city. Full consideration should be taken of the understanding gained thus far of the nature of urban developments at the city's periphery. The occurrence of urban exclaves devoted to such features as housing tracts, industrial parks, and airports can be quantified and placed into a tactics planning context. Computer simulation would allow for testing a wide variety of tactics and material. Table-top models would serve a training purpose.

From these data the degree of difficulty presented by a fortified city to an advancing army could be evaluated. It is wholly possible that radically new tactics could result from analysis of these models. The core of the city, for instance, might prove to be more vulnerable than the periphery.

The final general recommendation is simply that studies of urban characteristics relative to military considerations are only preliminary and should be continued and should be expanded both in number of cities studied and in types of phenomena examined. They should also be made more intensive. Given enough of these studies with enough measurements, there would be scope for making the kinds of generalizations which could be utilized with maximum effectiveness in contingency military planning.

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